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This document is the ninth in this series of reports to Congress as required by Section 5 of Public Law 94-475, 90 Stat. 2071. It describes the major research issues, trends and strategies of EPA's research and development program for the next five years.

Research needs identified in this year's report include: Toxic Substances and Pesticides, Hazardous Wastes, Air and Radiation, Energy, Acid Rain, Drinking Water, and Water Quality as well as several other issues which cut across media lines.

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Introduction

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1 Introduction

Introduction

Research Outlook 1984 is the ninth in this series of reports to Congress as required by Section 5 of Public Law 94-475, 90 Stat. 2071. It describes the major research issues, trends and strategies of EPA's research and development program for the next five years.

Strategic research planning is a two-way communication process which should help both researcher and regulatory official to appreciate better the long-term currents within which they plot their daily course. Effective strategic planning requires an integration of detailed scientific knowledge and long-range perspective. Detailed scientific knowledge keeps the strategic planning process realistic. A long-range perspective helps to lift strategic planning out of the beaten path and make it relevant to the future.

Prior to publication, the chapters of this report were reviewed by more than 100 scientists, research managers and environmental regulatory officials within EPA, other federal agencies, academia, private industry and public interest groups. The names and affiliations of these reviewers are presented in Appendix B of this report.

To a great extent, this year's Research Outlook builds upon, and is mirrored in, last year's report; it is the nature of the strategic planning process that one's five-year strategy not be re-invented, de novo, each year. Hence, one of the criteria for an effective long-range strategy is that it evolve gradually and logically over time and not be re-created with each year's annual plans.

Major Research Needs

The major research needs which were identified as paramount in last year's Research Outlook continue to be our highest priority research needs. These are:

Ground-water pollution. To control the pollution of ground water, it is necessary to be able to monitor underground pollutant plumes, to analyze the effects of the underground environment, and to predict the behavior of pollutants within that environment. This is one of our highest research priorities.

Toxicity measurement for complex mixtures. Determining the toxicity of a complex mixture of wastewaters as a whole would be a far less expensive process than identifying each of the components of the wastewater and then attempting to determine their combined effect. We are developing bioassay and other techniques that should improve our ability to determine the human health implications of such complex mixtures.

Water quality determination. The use ascribed to a body of water determines the quality at which that water must be maintained. A water-quality based regulatory approach requires that we develop accurate and inexpensive methods for determining water quality.

Toxicity prediction for chemicals. Testing chemicals for toxicity is an expensive and time-consuming process. We are at work developing test methods to expand existing chemical screening techniques.

Determining environmental exposure. In order to determine the effects of alternative pollution control strategies, we need to know exactly how much pollution people inhale, ingest and absorb during their daily lives. Using personal monitors, advanced detection techniques and models, we are developing accurate exposure data.

Acid rain source-receptor relationships. To assess the efficacy of, and need for, alternative mitigation strategies, we need better information on the relationships between the sources of acid rain precursors and their eventual effects on the receptors of that deposition. This is an issue of enormous resource implications for the industrial and commercial sectors.

Predictive modeling. In order to provide the necessary tools to state and local decision makers responsible for controlling air pollution, we will refine air pollution models to better predict the behavior of air pollutants under certain meteorologic and topographic conditions.

Biological pesticides and genetically engineered products. We expect a rapid growth in the development of biological pesticides and genetically engineered products. We are investigating better ways of evaluating the possible human health and environmental (non-target) risks of such agents.

Changes in Outlook

While an effective five-year strategy should display recognizable consistency from year to year, it should also adjust to, and change with, a changing environment. This report differs from last year's in three areas:

First, it treats the "cross-cutting issues" identified in last year's report in much greater depth. This is appropriate considering their importance to EPA's research program. The cross-cutting issues are relevant to most of the chapters (air, drinking water, hazardous wastes, etc.) of this report. These issues—biological screening, ecosystem health, groundwater protection and environmental modeling—are of such overriding import that they justify, and are given, their own chapter.

Second, some of the scientific and technical issues addressed have changed, some have been merged and a few have been eliminated. Such changes were necessary both to improve upon the logic of the presentation and to reflect changes in overall research priorities.

Third, we have added two topics — quality assurance and risk assessment covered in some depth in this report. These two topics are high-priority issues with regard to the management of the research process (quality assurance) and the use of the product of the research program (risk assessment).

Major initiatives have been underway with regard to both of these issues within the EPA for some time, and it is appropriate that they be covered in any discussion of our research strategy. Because of their uniqueness, these topics will be covered later in this introduction.

Most of the material presented herein came from the people directly involved in the research at one or more of our 14 laboratories located throughout the country and in research planning and management at headquarters. This information was reviewed in detail by representatives from EPA's regulatory program offices, by a special subcommittee of the EPA Science Advisory Board, and by a distinguished group of 45 external peer reviewers from academia, industry, other federal agencies and public interest groups. The comments and recommendations of each of these individuals were reviewed, and responded to, by the original authors. These individuals modified the earlier drafts as appropriate.

Long Term Trends

An effective strategy begins with a vision of the long-term trends within which the strategy is to be realized. While there are any number of trends which could be cited as influencing the gradual evolution of our research planning, we will end by listing a few of those which were an explicit part of the early stages in this year's exercise:

The aging of America. As our rate of population growth continues to be low, life expectancy continues to increase, and the World War II baby boomers grow up, our entire population is undergoing a truly monumental transition. Older people make up an increasing proportion of our population. From an environmental research perspective, this holds many meanings. First, environmentally caused health dysfunctions having a long latency period will now have more time to be expressed. Second, stresses early in life may be expressed through unexpected systemic dysfunctions much later. Third, older people are less resilient to environmental stresses and have slower recovery processes.

Chronic, low-dose exposures. Researchers are finding that there are few, if any, places on the earth which do not contain traces of anthropogenic substances, some of which are toxic. It is only within the last generation that people have grown to maturity in contact with these substances. Will this confound our efforts to set a baseline for environmental quality? How does one determine the relationship between 70 years of human exposure in the environment and six months for a rat exposed in the laboratory?

Multiple exposures to multiple chemicals. We have just scratched the surface with regard to testing the potential toxicities of a few of the chemicals on the market today. We know little about their synergistic effects. Are they additive? multiplicative? Are many small exposures worse than one large one? In real life people are exposed simultaneously to a number of pollutants in the air, water, foods and so on.

Protecting water supplies. The underground environment where much of our water comes from is being contaminated in several areas. That environment is, to a great extent, still a mystery to our science. We certainly need to know more about the physical, chemical and biological processes which control the quality of our underground water supplies.

The complexity of human systems. Science is gradually deciphering the complex systems which determine individual health and behavior. The long-term effects of substances on the neuro-behavioral system, the reproductive system, the immune system, etc. help to make us what we are. How pollutants effect these systems is largely unknown.

While these are but a few of the long-term trends which influence our research program, they do give some idea of the context within which we work to satisfy the agency's short-term needs for better scientific information. Next year's Research Outlook will delve more deeply into these and highlight more specifically our research response.

In the past year, we have looked carefully at our research activities and find that there are two which are of overriding importance. These not only apply to all of the chapters in this report, but they are relevant, in some way, to nearly every one of our nearly individual research projects. These two overriding issues are:

Quality assurance — What is the EPA doing to assure the accuracy and utility of the enormous volumes of data it is collecting?

Risk assessment — How can scientific knowledge be effectively packaged to describe the relative hazards of alternative policy choices?

In a large sense, therefore, these are the EPA's two highest priority research topics. They do not, however, fit comfortably into the output and research-oriented discussion which characterizes the rest of this report. They describe processes and, as such, rule over the context within which the state of science is determined. Hence, these are the first two topics discussed in *Research Outlook 1984*.

In the following discussion, we take these issues in turn. In addition, some mention of each of these topics is peppered throughout the rest of this document. We like to think that this is proof of both their importance and relevance.

Quality Assurance

All of the research discussed in this report would be of questionable value were it not for a rigorous and assiduously applied quality assurance program. Beyond that, the EPA relies upon its quality assurance program to assure that its regulatory and enforcement actions are based upon known and defensible quality and are valid for the laws and regulations that are to be enforced. EPA's quality assurance program addresses both monitoring and research activities. Since 1979, EPA's quality assurance (QA) program has been the responsibility of its research office.

Program Status

First, the current status of EPA's QA program. The form of the program (policies, procedures, management, etc.) is in place. However, the substance of the program (QA implementation and production of data of known and documented quality) has not been fully established. The EPA's goal is to have a complete and operational QA program in place by October, 1985 that will assure that all data reported from the agency's environmental monitoring and measurement activities are of known and documented quality. Current QA policies and procedures generally describe what is required for adequate quality assurance. Additional specific guidance will be produced to describe how to achieve the requirements.

Efforts to date in the monitoring and measurement community have emphasized QA and quality control (QC) for laboratory analysis. However, QA/QC is necessary in **all** data gathering activities including engineering, biological monitoring and testing, sampling and data reporting and interpretation. EPA's research will concentrate on how to assure data quality in those applications.

Use of reference materials and QC samples is a key step in evaluating analytical laboratory performance or the quality of analytical data. Reference materials are natural environmental samples that have been characterized for their composition. They are used to characterize the analysis of samples having a similar matrix and composition. Samples of such materials are generally submitted along with the routine samples as "unknowns" to the analyst. The accuracy of the results for the reference material are used to indicate the accuracy of the analysis of the routine samples.

Reference materials and QC samples may be used to characterize laboratory or analyst performance (i.e., sent as "unknowns" to the laboratory and the results used to judge the laboratory's ability to perform the analysis). They may also be used as known test samples to evaluate the quality of a new analytical method.

The agency's monitoring and measurement activities require analysis of a wide variety of matrices that are involved in questions related to the environment. A wide variety of QC samples are available for water analysis. However, in general, an adequate variety and supply (both composition and matrices) of reference materials and QC samples are not available to support the agency's needs in other areas.

The agency's environmental programs have constructed numerous data bases concerning different media. However, in some cases documentation of the quality of the data is not included in the data base. Therefore, the data cannot be used with confidence to support future decision making (e.g., to determine long-term trends).

Finally, guidelines are not commonly available to judge the acceptability of data produced in agency monitoring and measurement efforts. The acceptability of the data can be judged from three perspectives:

- acceptability of the performance of the analyst,
- use to which the data will be put, and
- the inherent limits of the specific method used when applied to the problem at hand.

Each of the problems and shortcomings mentioned above are being addressed in the agency's determination to assure a known level of confidence in the quality of its data. An Agency Task Force on Monitoring is working to strengthen our quality assurance efforts. EPA is also working with other agencies and professional organizations such as the National Bureau of Standards and the American Chemical Society to share its knowledge, adopt the latest and best techniques, and develop compatible quality assurance programs.

Strategy

Because of the complexity of the issue and the scope of its impact, the EPA's quality assurance (QA) staff is conducting a number of parallel efforts. First, it is auditing existing EPA programs. Emphasis is on assuring that EPA monitoring and measurement activities are adequately planned and on collecting appropriate QA information. EPA reports will include adequate statements on QA and the precision, accuracy validity and confidence limits in the data.

Second, efforts will be undertaken to develop scientific QA guidelines to be applied across all the programs on engineering, biological monitoring and testing, sampling and data reporting and interpretation activities. Where necessary, research tasks will be initiated to develop the organized technology transfer from different disciplines necessary to support these guidelines.

Third, the multitude of existing EPA reference materials, QC samples and QA activities will be reviewed, and recommendations developed to assure that such materials are available for use across all agency activities. The National Bureau of Standards and other potential sources of such materials will be explored. The objective here is to assure that a program is in place to provide reference materials and QC samples for all agency monitoring and measurement activities.

Fourth, our QA office will coordinate the standardization and publication of agency monitoring and measurement methodology. The methods will be published in a standardized format after all supporting data is reviewed, to classify the methods and assure that appropriate quality control guidance is included. This compendium of methods will be the official source of methods for use in agency programs.

Fifth, we will develop guidelines for assessing and reporting data quality for environmental measurements. These guidelines will identify data quality indicators to be used in agency data bases and to provide uniform assessment of, and standardized reporting requirements for, data quality.

Finally, we have begun to establish guidelines for achievable environmental measurement data quality goals. These guidelines are based on information available from controlled studies to identify method capability under optimum conditions, thus the data quality identified represents what can be achieved, not what might be routinely achieved across many laboratories.

The EPA's QA strategy is to assure that its QA policy for environmental monitoring and measurement is implemented throughout the agency's programs. Emphasis will gradually shift from establishing policy to assuring that the policy is implemented and providing technical guidance and materials to support implementation.

Experience has shown that a lack of adequate quality assurance ultimately leads to problems with data being too poor for defensible regulatory/enforcement decisions. In the last few years, the EPA has moved aggressively to see that its data is of known and consistently high quality.

Major planned research products include:

- Revised QA management plan, 1984
- Agency requirements for reference materials and quality control samples, 1984
- Guidelines for standard operating procedures for agency monitoring and measurement activities, 1984
- Guidelines for the development, evaluation and validation of measurement methods, 1984
- Guidelines for evaluating data acceptability, 1984
- Guidelines for air toxics quality assurance, 1984
- QA guidelines for biological testing, 1985
- Review of major agency data bases, 1985
- QA guidelines for engineering studies, 1986
- QA guidelines for field sampling activities, 1986
- Manual of EPA analytical methods, 1986

Risk Assessment

A risk assessment involves the review and analysis of relevant scientific information to provide risk managers (in this case EPA's regulatory decision-makers) with the latest best knowledge about a substance's hazard and exposure. Risk assessments are structured to enable regulatory decision-making (risk management) based upon valid and adequate scientific data.

Within EPA, risk assessments are produced for:

- the hazardous air pollutant program — health assessments are being prepared for more than 40 chemicals.
- the drinking water program — health risk estimates characterize risk control technology for pilot and field studies.
- the water program — comparison of risks and costs for sewage sludge management.
- the pesticides program — methods to estimate health and environmental risk from available data are being developed as well as health risk assessment methodologies for chemicals under review.
- the superfund program — human health effects assessment are being provided for single chemicals, complex mixtures, and site-specific situations.
- toxic substances program — human health and ecological risks are evaluated for both new and existing chemicals.

Acceptable exposure/risk levels are decided by policy makers who balance, to the extent permitted by law, estimates of risks with social and economic benefits from the uses of the chemical. Presently, quantitative risk assessments are being performed for carcinogenicity. Efforts are underway to develop quantitative assessment methods for mutagenic risks and reproductive effects risks and exposure-effects in environmental modeling.

State-of-the-Art: The first step is qualitative. Biomedical data is evaluated to answer the question, "How likely is the agent to be a cause of the effect under consideration." These kinds of assessments can be done for various kinds of effects such as mutagenicity, teratogenicity, and carcinogenicity. The likelihood of effect is expressed in terms of the preponderance of the biomedical evidence.

The next step is quantification. On the assumption the agent can cause the effect, what is the magnitude of health impacts for current and projected human exposures? The EPA routinely performs quantitative risk assessments for carcinogenicity only. The agency is currently developing the methods for performing quantitative risk assessments for mutagenicity, and will soon work on reproductive effects.

To provide quantitative estimates of carcinogenicity risk at the low levels of exposure generally found in the environment, we often must extrapolate from high doses in the observed range, usually involving animal bioassay studies, to much lower exposures involving human populations. Although a variety of mathematical models are available for such risk extrapolation, the ones most commonly used by regulatory agencies have been linear, non-threshold models.

Whenever adequate human data are available, it is used in preference to animal data for quantitative risk extrapolation. For human data, the best fit to the dose-response data is employed to extrapolate from high doses to low doses.

Negative epidemiology data are used to place upper bounds on risks.

Scientific Knowledge Gaps

The science of risk assessment is relatively new and has its own uncertainties and limitations. Many of the problems the agency faces in quantitative risk assessment involve extrapolation, i.e., making prediction on the extent of an effect upon human populations at low exposure levels from the degree of an effect upon laboratory animals at high dose exposure levels. For carcinogenesis there are a number of areas involving extrapolation that are being developed and refined through research:

Mechanisms of carcinogenesis: At the present time, the dominant view of the carcinogenic process involves the concept that most of the agents that cause cancer also cause irreversible damage to DNA. This position is supported by the fact that a very large proportion of agents that cause cancer are also mutagenic. Scientists suspect that the quantum type biological response characteristic of mutagenesis (the genetic material either is, or is not, mutated) is associated with a linear non-threshold dose-response relationship. That is, the greater the dose, the greater the probability of a response. This view is consistent with the relatively few epidemiological studies of cancer responses to specific agents that contained enough information to make the evaluation possible. Also, there is some evidence from animal experiments that is consistent with the linear non-threshold hypothesis.

Choice of mathematical model: We must depend on our current understanding of the mechanisms of carcinogenesis for guidance as to which risk assessment model to use. There is no solid scientific basis for a mathematical extrapolation model relating carcinogen exposure to cancer risks at extremely low levels of concentration. The plausibility of the upperbound estimates derived from the linear non-threshold model is based on: the correlation between carcinogenicity and mutagenicity, the non-threshold dose-response curve for mutagenicity in most cases, the quantum ("go" or "no go") nature of DNA interactions, and the linear nature of the dose-response curves suggested by some epidemiological data. Also, there is some evidence from animal experiments that is consistent with the linear non-threshold hypothesis.

Extrapolation from animals to humans: We rely upon the results of experimentation in laboratory animals to evaluate human hazard resulting from chemical exposure. There are enormous numbers of similarities and differences between humans vs. animals and even animal vs. animal. Many attempts have been made in risk assessment procedures to deal with these differences so that the test results from animals are as applicable to humans as possible.

EPA's Research Role

EPA's research program on risk assessment is in an early stage. Historically, the agency used data developed mostly by universities, private industry, or other governmental agencies to perform risk assessments. As the need for risk assessments has grown, so has the need to improve our own techniques and methods.

The agency has conducted risk assessment research in different media and has recently developed a specific research program on risk assessment in the intermedia arena. Within the agency, related kinds of research, as in mutagenicity, have improved our ability to do risk assessment. The agency has been supporting research at institutions such as the National Center for Toxicological Research which also provides data and information used in risk assessment.

EPA is constantly using data to improve its risk assessment capabilities. For example, with regard to animal-to-man extrapolation, improving on the understanding of metabolism is playing a key role in closing knowledge gaps.

Risk assessment has a wide variety of uses in the EPA regulatory offices. Research on risk assessment is found in various parts of research programs throughout EPA's Office of Research and Development. For example, much of the research described in the chapter on toxic substances and pesticides is directly applicable to use in risk assessments.

Major planned research products include:

- Refined risk assessment guidelines for cancer, 1984
- Refined risk assessment guidelines for mutagenicity, 1984
- Refined exposure assessment guidelines, 1984
- Development of risk assessment guidelines for reproductive effects, 1985
- Ranking of chemicals assessed for carcinogenicity under Superfund, 1985
- Development of complex mixture methodology for solid waste/superfund, 1985
- Completion of the correlation project for animal-man carcinogens, 1985
- Completion of approximately 40 hazardous air pollutant health assessment documents, 1987
- Evaluating the validity of extrapolation models for tumor promotors and initiators, 1988

2

Cross-Cutting Issues

Cross-Cutting Issues

Introduction

Major Issues

- Biological screening
- Ecosystem health
- Groundwater protection
- Environmental modeling

2 Cross-Cutting Issues

Introduction

As we mentioned in last year's *Research Outlook*, EPA's research addresses several issues which, by their very nature, cut across media lines. These topics do not fit comfortably within any particular program (air, water, etc.), and to discuss them within such a context would both unnaturally circumscribe the discussion and imply an inappropriate level of priority.

There are four major issues which are discussed in this chapter. These issues are too broad in their implications to be neatly shoehorned into any one chapter. These issues are:

Biological screening — What new techniques will open the door to accurate, low-cost ways to quickly estimate a substance's potential hazard?

Ecosystem health — What information do we need to collect to determine if an ecosystem is healthy or has been seriously disrupted?

Groundwater protection, analysis and control — How can we determine what happens to a pollutant and what mischief it can cause when it goes underground?

Environmental modeling — What is limiting our ability to effectively use environmental models, and what are the limits to their utility?

In the following discussion, we take these issues in turn. In addition, some mention of each of these topics is peppered throughout the rest of this document. We like to think that this is proof of both their importance and their relevance.

Biological Screening

Introduction

The hazard which a substance or type of effluent poses to aquatic life is a key part of effluent control decision-making. Without the ability to assess such hazard via an inexpensive and straightforward test, environmental regulatory agencies will be hard-pressed to establish a scientific basis for determining which discharges must be further controlled to protect aquatic life.

Current discharge limits are, for the most part, based on waste treatment technology. In some water bodies, such limits are insufficient to protect aquatic life. A toxicity test that can be conducted on a large number of discharges is needed. Acute toxicity tests exist which are both inexpensive and easy to conduct. However, the results often cannot be used to predict biological stream response. The responses observed in the biological community usually result from chronic, rather than acute, exposure.

Historically, short-term acute toxicity tests have been used to limit effluent toxic. However, recent findings indicate that most effluents are not acutely toxicity at discharge concentrations. Hence, a great deal of biological community impact may result from longer term chronic toxicity. This problem required the development of a rapid toxicity test and a means to provide an estimate of community impairment. In response, EPA researchers investigated the seven-day fathead and cerio- daphnia toxicity tests. Both of these organisms have wide distribution in the freshwater community. The combination of these two organisms, plus another such as a bacteria or algae, will comprise a sufficiently broad range of sensitivity to provide protection to the sensitive segment of the aquatic community.

The use of toxicity tests to evaluate treatment processes has been completed for the leather and tanning industry. The techniques need to be more generic. Additional studies are planned to strengthen the relationship between the chronic testing of receiving stream water and biological community response.

EPA's Research Role

The EPA has a major role in the research and application of short-term chronic toxicity testing. Industry, EPA regions, consultants and states are testing the usefulness of chronic tests developed by EPA researchers for inclusion in the waste-load allocation and permitting process.

Continued EPA research will improve the data base on the utility of *Ceriodaphnia* and fathead minnow as surrogate predictors of the aquatic community impacts. We will test effluents and receiving streams with simultaneous measurements of biological community response. The testing will span different biological communities and water bodies.

Extensive field studies will be undertaken to measure chronic toxicity of the receiving stream and effluents. Biological studies will be conducted at the same time to compare to the measured toxicity. Small river systems have been studied to date. Future studies will be undertaken on large rivers, lakes and estuaries.

A sufficient number of field studies need to be conducted where laboratory toxicity test results are compared with field data in order to insure that community impairment is accurately indicated through the toxicity tests employed. Effluent toxicity will be compared to ambient toxicity and ambient toxicity to impairment. Factors such as effluent no-effect levels, effluent discharge rate and stream flow will be considered in this evaluation.

Laboratory studies to increase the chemical data base for the seven-day *Ceriodaphnia* and fathead minnow tests will be undertaken in the initial part of the study. The most difficult issue is that of measuring and subsequently predicting persistence. Mass balance studies of toxic substances in flowing rivers will be used to gain an understanding as to how to estimate persistence. Laboratory tests will be developed to measure persistence of toxicity of effluents. These measurement techniques will then be related back to toxicity reductions in the stream. For selected industries, toxicity reduction studies through bench scale treatment process studies will be undertaken in conjunction with the field studies.

Major planned research products include:

- Develop data base for seven-day *Ceriodaphnia* and fathead minnow tests. Data will be obtained on test reliability, cost, difficulty and interlaboratory comparisons. This will provide comparison data to existing data bases and knowledge on relative sensitivity, 1985
- Develop short-term saltwater chronic tests, 1985
- Develop effluent tests to estimate toxicity persistence which can be related to receiving stream toxicity, 1986
- Demonstrate that toxicity tests can be used in the evaluation of treatment processes. This will provide permit writers with suggested methodologies for toxicity reduction, 1986
- Integrate single pollutant, combined pollutants, and complex effluent toxicity limits, 1987

Ecosystem Health

Introduction

How do we know when an ecosystem is healthy? When it has been severely disrupted? What terms best define the health of an ecosystem?

To protect the environment, we need to know what we want to protect. At the global level certain ecosystem functions, i.e., oxygen production, must be protected for the planet to maintain its life support characteristics. At the national and local level, decisions regarding protection are frequently made based on the desired use of the ecosystem.

Once such a use has been resolved, how can we protect or promote the health of a system such that its use is not impaired and how do we measure it? How does a potential stress (e.g., effluent discharge, acid deposition) affect an ecosystem and how do we recognize it when it happens? In order to prescribe corrective and/or preventive measures, we must be able to measure and determine the desired nature of the ecosystem.

Background

All ecosystems have the basic qualitative characteristics of energy fixation, material cycling, and ecosystem structure interacting in a complex manner. However, each ecosystem will have quantitatively different levels of these characteristics and degrees of interactions between components. These characteristics are in a constant state of flux over time and space both with and without the influence of man. This complexity in characteristics makes the determination of the health of an ecosystem an equally complex problem.

Given these complex systems, what do we measure? Are there critical and sensitive components which we can use to define and monitor the system? In spite of the complexity of interactions and the interdependence of organisms, it has been demonstrated that, in certain communities, a particular species may be a key species in maintaining community structure and organization. In addition, some species such as Douglas fir in the Northwest or lake trout in the Great Lakes, may be socially or economically desirable. Therefore, there are instances when particular species are important to protect: their loss may cause major shifts in communities or economic loss.

The question, therefore, becomes one of trying to find underlying principles which may be used to define both the current state and the normal (desired) state of an ecosystem. There are a few key steps to answering this question.

Major information needs are:

Identification of critical and sensitive components: Within the context of any one ecosystem or community there may be particular components; i.e., processes, species, that are critical to the system and sensitive to stress. The species critical for economic reasons are relatively easy to identify. The difficulty arises when trying to identify ecologically critical species.

Generalizations between ecosystems and types of stress: The ability to recommend specific measurements for ecosystem evaluations depends in part on the degree to which critical and sensitive components are system and stress dependent. The sensitivity of systems is known to be influenced by environmental conditions such as temperature, water quantity and quality, salinity, etc. Can ecosystems be categorized such that certain critical and sensitive components can be recommended for each category? Each type of stress? Although many comparisons of toxicants have been made on single species in the laboratory, little data are available for ecosystems.

Determinations of "acceptable" levels of stress: The activity of man will inevitably result in changes in ecosystems. What are the attributes of ecosystems that contribute to recovery?

Monitoring of normal ecosystem fluctuations: Therefore, there is a need for continued study of unstressed systems and the normal fluctuations in system behavior. This information will also help to distinguish stress from natural conditions.

The subject of ecological health is one which encompasses the research of many organizations. The EPA plays a major role in developing information on the effects of stress on ecosystems. In general, these research efforts are applied toward specific problems. The development of early warning systems and the applicability of laboratory test results is an area of particular emphasis at this time.

In addition to the EPA's laboratories the EPA-funded Centers at Cornell University and the University of Rhode Island are expected to play an important role in integrating ecological theory and marine sciences with the evaluation of toxic stresses. Additional federal agencies active in ecosystem studies include the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the U.S. Forest Service.

Research Strategy

Our current studies in ecosystem health research include the applicability of water quality criteria in outdoor experimental streams, and other field sites, an evaluation of the EPA's pesticide hazard evaluation protocol in natural temperate ponds, laboratory microcosm research evaluating potential toxics testing protocols, complex effluents toxicity in natural streams, research on toxics in the Great Lakes and its tributaries, and an experimental lake acidification project.

EPA studies with microcosms and freshwater streams and effluents are designed such that a variety of different toxicants will be tested. In this manner the degree of generality about the toxicant dependency of stress responses can be evaluated. By comparing results with similar studies in other types of systems, the ability to generalize between systems could be investigated. For example, the results of current EPA studies on the effects of pentachlorophenol (PCP) in freshwater streams could be compared with the results of the studies on the effects of PCP in freshwater ponds at the U.S. Fish and Wildlife Service laboratory at Columbia, Missouri.

Other EPA freshwater stream and microcosm studies include testing a series of exposure concentrations so that dose-response curves can be prepared. The effluent field evaluations rely on down-stream dilutions to provide a stress gradient. These studies will help evaluate the concept of thresholds in ecosystem resistence to stress.

EPA research undertaken as part of pesticide pond, Great Lakes, and lake acidification studies use natural systems. Data will be obtained on the normal characteristics and fluctuations of ecosystems thus providing information aiding our ability to distinguish stress effects from normal variations.

As a cross cutting issue, the EPA research projects which contribute to the information needs described above are part of other research programs. There is an increasing emphasis on field studies and ecosystem evaluations which is expected to increase in importance over the next few years. As these studies are developed and completed, overall trends can be evaluated and hypotheses or principles formed to guide further studies. Answers will not be straightforward or quick to obtain. The complexity and variety of ecosystems and their responses to stress, assure that difficulties will arise. Therefore, objectives directed toward these issues should be considered to be long-term in nature.

Groundwater Protection

Introduction

Groundwater supplies are extremely important. They account for nearly half of our drinking water and a large portion of the water used for irrigation. They are also vulnerable to contamination and difficult to clean up once contaminated. And, compared with other aspects of environmental protection, we know very little about what happens when pollution goes underground.

To adequately protect ground-water quality, EPA and the states must be able to: identify the sources of ground-water pollution, estimate the change in concentration of pollutants from their entry into the subsurface to point of exposure to humans, determine the health effects of such exposure, and develop technological and financial data relating to protecting clean ground-water and cleaning up already polluted groundwater.

Much of the research on the health effects of, and control of, drinking water contaminants is directed towards chemicals found in ground-water. Research to develop and evaluate technology for control of sources (such as surface impoundments) also supports effective ground-water protection decisions.

Background

The scientific capacity to assess and predict the impacts of groundwater pollution is meager but improving. In the past few years important gains have been made by EPA research in technology for accessing the subsurface and taking samples that are uncontaminated by the sampling process. Further, we have determined how a few organic chemicals behave in a few geological materials. However, current groundwater monitoring techniques are cumbersome, expensive, and insufficiently precise, and our capability for predicting the behavior of organic and microbiological contaminants is severely limited. To address these issues our research is focused upon two areas: monitoring and prediction.

In the *monitoring* area, significant progress is being made. For example, three particularly promising ways to expedite and improve subsurface investigations are geophysical techniques, sampling for organic chemicals in the unsaturated (vadose) zone, and improved approaches to groundwater sampling.

Geophysical sensing techniques, originally developed for mineral resource exploration, may prove invaluable as subsurface monitoring methods. Such techniques include use of metal detectors and magnetometers, ground-penetrating radar, electromagnetic induction, resistivity and seismic techniques. Sampling techniques for measuring gaseous emissions in the soil column include isolation flux chambers for capturing emissions at the surface or at varying depths, subsurface probes containing Draeger tubes, and portable gas chromatographs. These techniques remain largely in the experimental stage.

The major research in this area is shared by the EPA and the U.S. Geological Survey, with some contribution from the Department of Energy. The petroleum industry is a continuing source of technology, especially in geophysical techniques.

To *predict* the impact of groundwater contamination on underground sources of drinking water, a sufficient understanding of the behavior of contaminants in the subsurface is required. A number of things are known:

- Most heavy metals are relatively immobile in ground-water when present as cations. Those which may exist as anions (Cr, etc.) are likely to be highly mobile and cause serious pollution problems.

- Nitrate is usually quite mobile and fairly persistent in ground-water.

- Low molecular weight halogenated aliphatic hydrocarbons (methanes, ethanes, ethenes, propanes) are very mobile and persistent in ground-water.

- Many other synthetic organic compounds, including aromatic hydrocarbons, phenols, and ethers, have shown sufficient mobility and persistence to have been detected as ground-water pollutants in field studies.

These are only qualitative observations. To adequately protect groundwater supplies, we must be able to make quantitative estimates of contaminant concentrations at points of withdrawal or discharge. This requires adequate predictive tools which depend on an understanding of the physical/chemical, hydrological, and biological processes controlling transport and fate.

The major scientific and technical information gaps which restrict our ability to make accurate predictions of the impact of contamination include:

- Inability to estimate the non-uniformity of formations, resulting in inaccuracies in groundwater movement prediction.

- Inability to predict sorption of non-polar hydrophobic compounds (e.g., chlorinated ethenes, trihalomethanes, chlorinated ethanes, chlorinated aromatics, benzene) in geological materials of low organic carbon content (less than 0.1%), which are particularly prevalent in the deeper subsurface.

- Lack of knowledge about the contribution of chemical/physical processes other than sorption (e.g., surface-catalyzed reactions) to changes in the concentration of subsurface pollutant.
- Inability to predict biotransformation, the key process affecting pollutant attenuation in the subsurface.

The major research on processes affecting organic chemicals in ground-water is shared by EPA and the U.S. Geological Survey. Research in other countries is accelerating, especially in Sweden, Switzerland, the Netherlands, Israel, and England. Research on virus transport and survival in the subsurface is supported solely by EPA.

Research Strategy

To improve our *monitoring* capability, our research will evaluate geophysical and geochemical methods for detection and mapping of subsurface leachates and groundwater contaminant plumes. A variety of methods will be evaluated at hazardous waste sites selected in coordination with EPA's regional offices. Sites selected will test the techniques against different types of targets (e.g., plumes of conductive contaminants or volatile organics, hydrocarbon lenses) in different hydrogeologic regimes (e.g., arid Great Basin hydrogeology, Northeast aquifers with substantial surface recharge).

With regard to *downhole sensing*, research strategy is to survey, develop, test, and evaluate sensors and methods which can be used for hazardous waste site monitoring and for preconstruction hydrogeologic investigations. Focus is on small diameter, shallow-depth boreholes. Laboratory studies will assess electrical properties of porous media for application to geophysical measurements. A survey is being made of the full array of existing downhole sensors. The data obtained will be evaluated to determine to what extent the equipment can be used, with or without modifications, for hazardous waste site monitoring. Useful sensors will be field tested.

With regard to *vadose zone* monitoring, planned research will examine available methods and prepare guidance for installation and operation of devices and interpretation of their data. Monitoring in the unsaturated zone is designed to detect leaching and percolation of pollutants from hazardous wastes before the pollutants reach the water table. Planned research will examine existing equipment, determine installation and operational procedures, establish equipment limitations, and describe methods for data interpretation. Research will be principally concerned with monitoring the movement, especially of fast moving organic compounds, in the shallow subsurface at hazardous waste land treatment areas through core-water and pore-water sampling.

To date, the suction cup lysimeter has been the most commonly used technique for obtaining water samples from the unsaturated pores of the soil and shallow (less than 2 meters) zone. Research will determine the variables that affect the performance of suction samplers. Planned research will also examine the potential application of vadose zone monitoring equipment to landfills and surface impoundments. Suction cup lysimeters are also subject to plugging and other operational problems. Our research will examine the limitations of this technology and evaluate possible remedies.

Indicator parameters for ground-water monitoring can be used to detect the presence of hazardous constituents in groundwater. Indicator parameters are constituents chosen because they are easy to measure and because their presence indicates the presence of other substances of concern. A data base will be developed using data from existing records of Consent Decree, Superfund, and RCRA site monitoring files. EPA researchers will test the rate of migration of selected indicator parameters with other hazardous constituents of concern.

Indicator parameters will be selected according to waste type, hydrogeologic considerations, and detectability above background values. Questions to be investigated are: What are the seasonal fluctuations in groundwater parameters such as pH, temperature, specific conductance, and TOC? What are the actual correlations between the indicator parameters and the hazardous constituents of interest? What classes of hazardous constituents are missed by the current monitoring requirements which employ indicator parameters? What indicator parameters or other technique can pick up these "missed classes" of hazardous constituents? For given types of wastes, what are appropriate sets of indicator parameters, and under what conditions are they reliable?

EPA's research over the next several years will emphasize techniques for identifying and mapping hydrocarbon plumes of contamination and implanted sensors for detecting and quantifying specific organic chemicals.

Our groundwater *prediction* research seeks to be able to predict the environmental impact of chemicals and pathogens which escape into the environment and into the subsurface. The research approach is to identify both characteristics of chemicals that have similar transport behavior and characteristics of geological materials which have similar effects on pollutant behavior in the subsurface. The ultimate goal is to be able to identify a few characteristics of a chemical (or pathogen) and a few characteristics of a geological material and be able to predict the kind of environmental impact which would result.

The prediction research strategy addresses the major processes affecting contaminants in the subsurface: biological, physical/chemical, and hydrological. Each process is studied both from the view point of chemical parameters and subsurface parameters. Field and laboratory studies of each process will contribute to the mathematical models as well as the data base on pollutants. Likewise, information gained in other research on individual pollutants contributes to the data base on pollutant parameters, while the mathematical models of water movement and solute transport are modified to include process descriptions. In turn, the mathematical models are used to help design laboratory and field studies. Such models may range from the very simple to the very complex and multidimensional.

The EPA program concentrates on biological and physical/chemical processes affecting organic pollutants and viruses in the subsurface. Hydrologic processes are well described and modeled due to extensive efforts by the U.S. Geological Survey.

The increased understanding of sorption and biotransformation gained by laboratory and limited field studies through 1985 should allow this research to move toward more field-oriented research in the 1986-1989 time frame. The field studies will evaluate the increased understanding of the processes gained by laboratory studies as well as evaluate the accuracy of the new models. At the same time these field evaluations will demonstrate the integration of mathematical modeling with monitoring design (both advanced and conventional techniques) to show the most cost-effective procedures for groundwater investigations.

Major planned research products include:

- Use of geophysical methods to map injection well fluid movement, 1985
- Guidelines for monitoring the vadose (unsaturated) zone, 1985
- Design specifications for an organic chloride fiber optics detector, 1985
- Effect of naturally-occurring organic subsurface material on abiotic and biotic processes, 1985
- Effects of initial contaminant concentration on biological processes, 1986
- Definition of important parameters which determine behavior of low molecular weight, volatile organic chemicals, 1987
- Definition of important characteristics of geological materials which will allow grouping by influence on contaminants, 1988

Environmental Modeling

Mathematical models are scientific, technical, and decision making tools whose development, application, and utility cut across all program areas, environmenta media and scientific disciplines. In simple terms, models are quantitative mathematical expressions of hypotheses, ideas, concepts, or observations that permit pertinent information and data to be assembled, processed, and evaluated. In this context, the development and application of models in the broad environmental field provides: guides for data collection, frameworks for assessing available information and data, techniques for evaluating complex interactions including control strategies, and tools for predicting environmental effects over a wide range of situation and conditions.

Our ability to develop and use environmentally related models is limited by our inability to accurately perceive, measure, and mathematically describe real environmental systems, organisms, or events. The inability to describe, quantify, and interpret model uncertainty for any real application is itself a major research and development subject. This need is closely related to another problem—that of adequately conducted and documented field evaluation studies.

Although research and development activities related to specific modeling needs are discussed within the other chapters, major generic issues remain. To date most environmental models (air as well as water) have been designed to deal with so called "far field" situations where the pollutant loads are assumed to be relatively well mixed into the transporting media and the time frames run from days to years. With increasing emphasis on multimedia exposure and risk analyses, however, "near field" conditions become extremely important. Modeling "near field" conditions (e.g., zones in and around discharge plumes and zones along highways and in building canyons, etc.) requires improved characterization physical, and biological factors of the environment that must be modeled. "Near field" modeling may also have much shorter time sequences (minutes to hours) and highly variable concentrations. As a result, simplified computational procedures are required to analyze the greatly increased volumes of data in order to reduce computational costs. More sophisticated statistical and probability distribution techniques are required for estimating average and minium/maximum concentrations and conditions.

As environmental modeling techniques are improved and as decision-makers require greater accuracy, there is an increased necessity to provide better estimates of multimedia source emissions in terms of time-varying source compositions and strengths. This is particularly important for "near field" problems and for model evaluation studies.

Another major generic problem is that of linking environmental exposure models with human and environmental health submodels. Most previous air, water and terrestrial model development efforts resulted in estimates of the concentration of chemical contaminants in various ambient media (i.e., estimated environmental concentrations). Concurrently, effects models have most often dealt with dose responses once the chemical contaminant is inside the organism. Thus, a linkage problem exists. How much of the pollution outside of an organism gets inside? This problem includes characterizing the population exposed in terms of its spatial and temporal behavior and in understanding the movement of the chemical into the organism.

Improvements also are needed in the model-user interface. Many environmental models are so large, complex, and dissimilar in operation that users have difficulty in developing input instructions to obtain the information they need. Thus, the development of standard, simplified software for use with a variety of models would help the average user apply them to his problems. Such software interfaces and overlay techniques could be designed for the low-cost micro-computers that are now in widespread use.

Finally, limited user support continues to restrict the efficient use of models for environmental decision making. After models have been developed and are in use, there are often no programs to obtain user feedback to improve and maintain the model codes or to distribute updated programs, magnetic tapes, user's manuals or to provide on-line assistance. The development of central sources for environmental model user information, such as EPA's Center for Water Quality Modeling, is intended to promote the wider use and greater utility of environmetal models.

3 Toxic Substances And Pesticides

Toxic Substances And Pesticides

Introduction

Legislative Mandate

Major Research Topics

Estimating Exposure: What methods are needed to estimate exposure of humans or other organisms to pesticides or toxic chemicals?

Predicting Response: What tests are needed to predict environmental and human responses to pesticides and toxic substances?

Structure Activity: How does a chemical's structure relate to its environmental and biological activities, and to what extent can this relationship be used to screen chemicals for potential health or ecological effects and to set priorities for chemical testing?

Biotechnology: What health and environmental research is needed to support assessment and regulation of biological control agents or genetically engineered organisms?

Release and Exposure of Chemicals: What engineering research is needed to develop predictive capabilities in assessing release and exposure of chemicals into the environment and to determine best control measures to mitigate these releases and exposures?

Long Term Trends

3

Toxic Substances And Pesticides

Introduction

Toxic substances, and their consequences for public health and the environment, have become matters of intense scientific, public and regulatory concern. The problems and the comprehension of toxic substances in the environment is rapidly evolving. New chemicals are entering the market, the use of pesticides is ubiquitous, and science is discovering previously unknown relationships between chemical substances and biological processes. More than a century of industrial development and agricultural modernization have left behind a legacy of products and by-products of toxic substances. Some of these chemicals are hazardous to humans, plants or animals. If used with careful controls, these synthetic substances can be extremely beneficial. If used inappropriately, they can be detrimental to humans and to the stability of the environment.

The Toxic Substances Control Act (TSCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) provide the legislative mandate for our research in this area. EPA reviews all new chemicals and pesticides to ensure that they do not pose unreasonable risks to health or the environment. To do so, EPA must know of the characteristics of chemicals and of the most advanced scientific knowledge about their effects.

EPA's toxic substances research program is evolving in several ways including closer merging of exposure and response studies, shifting of ecological studies from a single-species focus to emphasis on complex system dynamics, and further development of information on the relationships between chemical structures and their biological activities (SAR).

Long range trends that influence our research priorities include changes in the mix, products, and location of industry, especially the chemical industries; dependence on untreated groundwater for potable supplies, expansion and relocation of agricultural activities, also biotechnology and changes in the age structure and health of the population which may affect sensitivity to chemicals. Other developments within the scientific community influence our research focus. These include the rapid advances in our understanding of immunology, virology, neurobehavioral effects, reproductive dysfunction, genetic disease or heritable mutation or mutation, cardiovascular disease, biotechnology and the origins of cancer.

Decisions about the control of toxic chemicals and pesticides require accurate information about the benefits and risks of each substance. EPA's toxic substances and pesticides research programs are dedicated to maintaining and improving the quality of this information.

The toxic substances and pesticides research programs respond to specific research objectives in support of EPA's enforcement and regulatory functions. Although each of the two research programs has a separate budget and legislative mandate, much of the research being done and many of the scientific questions being addressed are relevant to both programs. As a result, the integration of the information on pesticide and toxic chemical research that began in the *1983 Research Outlook* is hereby carried further, with unified discussions of exposure studies and research on biological responses.

In addition to supporting research projects, EPA's program investigates the scientific literature and follows relevant projects of other federal agencies such as the National Institute of Environmental Health Sciences, the National Cancer Institute, the Food and Drug Administration, the National Center for Toxicological Research, and the National Institute of Occupational Safety and Health.

This chapter explains the major research themes of EPA's Office of Pesticides and Toxic Substances, describes our major research objectives within each theme, and indicates the EPA research activities under way and planned to meet those objectives.

The toxic substances and pesticides research effort for fiscal year 1984 is allocated $30.8 million. This total is divided among the two programs as follows: toxic substances research, $24.5 million million, and pesticides research, $6.3 million. The total resources for the toxic substances and pesticides research program are distributed among the major research areas as follows: environmental processes and effects — 33%, health effects — 43%, monitoring systems and quality assurance — 17%, stratospheric modification — 2%, and scientific assessment — 2%.

Our research program seeks to answer the major unresolved scientific and technical questions which detract from effective environmental protection. For the toxic substances and pesticides research programs, the six highest priority research themes are as follows:

Major Research Topics

Estimating Exposure: What methods are needed to estimate exposure of humans or other organisms to pesticides or toxic chemicals?

Predicting Response: What tests are needed to predict environmental and human responses to pesticides and toxic substances?

Structure Activity: How does a chemical's structure relate to its environmental and biological activities, and to what extent can this relationship be used to screen chemicals for potential health or ecological effects and to set priorities for chemical testing?

Biotechnology: What health and environmental research is needed to support assessment and regulation of (1) biological control agents or (2) genetically engineered organisms?

Release and Exposure of Chemicals: What engineering research is needed to develop predictive capabilities for assessing human exposure and environmental release to chemicals in the environment and to determine best control measures to mitigate these releases and exposures?

Legislative Mandate For Toxic Substances

The Toxic Substances Control Act (TSCA) establishes EPA's authority to regulate, if necessary, all commercial chemicals except those uses specifically exempted in the act.

Section 4 of TSCA gives EPA the authority to require manufacturers and/or processors to test their chemicals for health or environmental effects. This authority is selective, applying only to those chemicals for which EPA makes certain findings as to the need for testing. Testing requirements under Section 4 are imposed by rule, each rule specifying not only the chemical to be tested, but also the nature of the required tests. EPA's Office of Toxic Substances uses both negotiated test rules and mandated test rules to implement Section 4.

Section 5 of TSCA establishes a premanufacture notification process for all new chemicals or significant new uses of existing chemicals. The manufacturers of these chemicals are required to submit information to EPA for review prior to production. Unless EPA finds that the chemical poses an unreasonable risk or demonstrates the need for additional testing, the chemical is placed on the EPA inventory of existing chemicals.

Sections 6 and 7 of TSCA provide control authority for existing chemicals. Section 6 is general regulatory authority and Section 7 gives EPA special powers to address imminent hazards. Section 8 provides EPA with information-gathering authority. Using these three sections, EPA can limit or ban the production, distribution, disposal or use of chemicals to prevent unreasonable risks to health or the environment.

Legislative Mandate For Pesticides

EPA's legislative authority to regulate pesticide use comes from the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and Sections 180, 193 and 561 of the Federal Food, Drug and Cosmetic Act (FFDCA). FIFRA gives the EPA responsibility for determining the standards for registration of pesticides for legal use in this country. Section 3 of FIFRA provides EPA with the authority to regulate the use of pesticides in a manner which will not result in unreasonable adverse effects to the public health and the environment. Sections 180, 193 and 561 of the FFDCA provide EPA with the authority to set tolerances and exemptions for pesticides in food crops and in animal feed and food additives.

To obtain registration for a pesticide, a manufacturer must first test specific health and safety aspects of the substance using testing guidelines suggested by EPA. Results of these tests are then submitted to EPA, which decides either to register the pesticide for general or restricted use, to request more information from the manufacturer, or to deny or revoke registration. When a pesticide is registered, EPA specifications for it include allowable use, means of production, disposal requirements, crop residue limits, and tolerances in animal feeds and food additives.

The Registration Standards Program involves an intensive review of the data base supporting already registered chemicals. The Special Review Program includes risk/benefit reviews of registered pesticides when there are effects exceeding established criteria for "reasonableness". Special reviews may be launched if such criteria are met or exceeded during development of a Registration Standard, or because such information is made known to EPA.

The function of EPA's research within the legislated context is to develop tests for accurately assessing health and environmental hazards and exposure and for assessing risk in support of the registration process, the special review process and enforcement, and to provide quality assurance and technical evaluations.

Estimating Exposure: What methods are needed to estimate exposure of humans or other organisms to pesticides or toxic chemicals?

In making regulatory decisions, EPA is concerned with the risks to humans and to the environment. Risk is a factor of exposure to the agent as well as of its toxicity. Models are useful tools for estimating exposure and risk. However, models cannot answer all or even most of our concerns of exposure or effects. It is necessary to recognize both the utility and limitations of such models in risk assessment. In addition, many existing models are insufficiently validated.

Mathematical models are highly complex, and improving their reliability is an exacting task. The models are made up of components that represent actual conditions in the field. The exposure component is partially described in terms of chemical concentrations in air, water, soil and food and then coupled with data on human intake, absorption, and metabolism. The hazard component identifies and measures potential adverse effects to organisms, and is derived from biological analyses and stated in biological terms. Although mathematical models are available for defining hazards, they are still in the beginning stages of development. These components must be integrated in order for the model to be useful in assessing environmental risks.

At present, the models for transport and fate are being modified to improve the accuracy of their predictions of environmental concentrations of pesticides and toxic substances. After the modifications are made, the models will be validated in microcosms and in the field. Improvements are being made along several lines, including integration of single-medium models into multi-media models and development of models to predict concentrations when the source input varies with time.

Researchers also will incorporate data from specific research projects, such as one which will take a census of terrestrial non-target organisms at a pesticide spray site. Planned field studies include model validation through replication of actual pesticide use conditions. A cooperative study between EPA and the U.S. Geological Survey in Dougherty Plain, Georgia will gather field data on the migration of pesticides through soil to groundwater. The results will be used in evaluating several predictive leaching models. Also, there will be an assessment of groundwater contamination by Temik in Florida and the resulting potential for health effects.

Studies will also be designed for pesticides used against specific pests. A field study using actual mosquito control pesticides with an organophosphate or carbamate base applied to ponds will measure population changes in the pond's non-targeted organisms, as well as brain acetylcholinesterase and pesticide residues in fish, aquatic vertebrates and food. Development of a mosquito pesticide model will be coordinated with a regional mosquito control program in a Midwest area.

Much of the effort on estimation of pesticide exposure involves review and screening of data available through the pesticide registration process. To assist in handling the large volumes of data generated under TSCA, a growing research effort is directed at pattern recognition and other data reduction techniques and at improving computer programs for presenting and relating diverse data sets.

One approach taken in the exposure research is to use existing data and case studies for the validation. One such case which will be pursued involves validation of an estuarine exposure model using field data collected from the Kepone contamination of the James River and estuary.

The health risk assessments mandated by TSCA require exposure assessments which are based primarily on data collected for other purposes. With exposure an increasingly important factor in EPA regulations, research in this area is focused on improved methods for collecting exposure data. In particular, portable monitors and biological tests to document exposure in individuals will be developed for specific chemicals of concern. Methods will be developed, using questionnaires and statistics, to relate individual measurements to larger populations. In addition, field sampling techniques will be developed to monitor exposure pathways, both to provide data and to validate predictive models.

Finally, our ability to estimate risk to humans is limited primarily by a lack of understanding of the fundamental biological factors which govern dose-response and the ultimate manifestation of human disease. Human data is often difficult to obtain; controlled studies of chronic exposures are virtually impossible and retrospective epidemiology is plagued by the difficulties of exposure estimation and confounding variables. In the absence of controlled human experiments or reliable quantitative epidemiology, risk estimates must be based upon a wide range of bioassays and animal experiments. The two key factors here are extrapolation from high to low dose and from experimental animals to man (see the discussion of risk assessment in the "Cross-cutting Issues" chapter). To reduce the uncertainties associated with existing risk methodology, research will focus on improving methods for extrapolating from animal data to human risk, and from high dose to low dose, of mutagenesis, carcinogenesis, and other potential adverse health effects. In addition, we are investigating the potential use of selected epidemiological studies to improve the data base.

Our approach will be to evaluate test methods to select, for relevant toxic chemicals, the animal species or other test system which most closely approximates responses observed in humans. For example, short-term bioassays will be evaluated using asbestos (a known human carcinogen) and other fibers to determine the correlation of certain short-term tests with tumorigenesis in whole animals.

Major planned research products include:

- Results of a field study using non-toxic tracers to define atmospheric release of gases and fine particulates, 1984
- Field testing of mathematical descriptors for biodegradation in estuarine sediments, 1985
- Models to estimate human exposures to organic chemicals, 1985
- Subsurface transport and transformation models, 1986
- Predictive model for dose effects of asbestiform minerals, 1986
- Extrapolation models for estimation of neurotoxic risk to humans, 1988

Predicting Response: What tests are needed to predict environmental and human responses to pesticides and toxic substances?

Pesticides and toxic substances can cause a variety of biological responses. The responses may be inconsequential or serious, transitory or irreversible. However, there is much less known about the detection, measurement and importance of subtle effects on growth, genetic material, and specific organ systems.

EPA's research on pesticides and toxic chemicals includes continued efforts to identify, measure and evaluate biological responses (endpoints) of medical significance.

This entails the development of new testing systems using different organisms, rationales and/or analytic techniques. In the health area, the selection of animal test systems most appropriate for prediction of adverse effects on humans continues to receive high priority. Studies are planned on dermal absorption and other up-take routes, the different responses of organ systems, and the relative sensitivity of an individual in stages of development from conception to adulthood. Chemical toxicity to genetic material, because of its key role in carcinogenesis and heritable mutations, continues to receive special attention.

Compared to tests for human health responses, methods to estimate environmental effects on populations, communities and ecosystems are in an early stage of development. The lack of such methods can be problematic. It is important, for example, that EPA be able to predict, from test results, the possibility of reproductive failure in an entire population. Likewise, there is a need for estimation of the community consequences of changes in relative densities of key species and the ecosystem implications of changes in nutrient cycling. Some of the effects, crop loss or reduction in fish of commercial value, are of obvious economic importance. Others, such as reduced assimilative capacity in a wetlands ecosystem, are more difficult to quantify.

EPA's research on environmental toxicology is shifting from single-species bioassays to tests with complex systems. This is accompanied by increasing efforts to determine the applicability of laboratory results in the prediction of ecological effects under field conditions. Extrapolation from laboratory to the field is necessary because field measurement of population, community, and ecosystem changes is complex and expensive.

The goal of this research is to develop laboratory methods which correlate closely with field measures of significant health or ecological effects. The health-related research, combined with complementary studies at the National Cancer Institute, National Center for Toxicological Research and the Food and Drug Administration, will help to bridge the gap between laboratory data and human epidemiology. The ecological research, combined with studies sponsored by the Fish and Wildlife Service, Department of Interior, will help in the extrapolation of laboratory results to field effects.

Major planned research products include:

- Test methods for use in measuring adverse health effects: cardiovascular disease (1984), immune system impairment (1985), mutagenesis (1985), reproduction (1985), cancer (1986) and liver/ kidney impairment and disease (1986).
- Criteria for judging the usefulness and validity of test results in freshwater, system-level assessments, 1984
- Tests for predicting effects of toxic chemicals in marine systems, 1985

- Field validation of laboratory-derived, microcosm, bioassay and effects test methods, 1985
- Assessment methodology for human heritable effects of chemical exposure, 1985
- Development of short-term, inexpensive methodology for identifying the teratogenic potential for chemicals, 1985
- Short-term testing methods for specific neurophysical, neurochemical and neurobehavioral changes to screen for the effects of toxicants, 1986
- Methodology for the prediction of potential reproductive toxicity which may be used in determining the need for two-generation animal studies, 1986
- Catalog of terrestrial and environmental responses to pesticides and toxic chemicals, 1988

Structure Activity: How does a chemical's structure relate to its environmental and biological activities, and to what extent can this relationship be used to screen chemicals for potential health or ecological effects and to set priorities for chemical testing?

Careful studies of molecular structure and specific activities indicate that compounds which are similar in chemical structure, physiochemical properties or other factors may have similar biological activity or effects. These correlations are called "structure-activity relationships" or SAR.

Structure-activity relationship analysis is one of EPA's approaches to the evaluation of new chemicals under the premanufacture notification (PMN) program. Most PMNs are accompanied by few test data on health or environmental effects. Where appropriate, EPA employs SAR analysis to set priorities among PMNs in terms of potential hazard and to build the case for requiring testing under Section 5(e) of TSCA. Similarly, SAR may be useful in evaluating requests for PMN exemption or to guide in the selection of the most appropriate tests for existing chemicals under Section 4 of TSCA.

Within limits, and in the absence of data to be used instead of SAR, the SAR approach is useful in screening chemicals for further evaluation and setting priorities for testing. In some cases, existing knowledge may support use of SAR in estimating environmental fate and biological effects. Were a verified SAR methodology available, data collected and validated on one chemical of similar structure or characteristics could be applied to another chemical of similar structure.

EPA's research program on SAR began with a review of research done by the FDA, chemical companies, and private laboratories. Data on a wide variety of compounds are being collected from these sources and from EPA's research to identify useful correlations and define the applicability and limitations of recognized correlations. Other organizations involved in SAR research include the Food and Drug Administration (with emphasis on human health effects) and a number of industrial, private organizations and academic institutions.

EPA's research into SAR has both environmental and health effects components. The environmental research on SAR has two objectives: to expand the data base of correlations, and to determine the cause-effect relationships between a chemical's molecular structure and its behavior in organisms or the environment. The research program carefully considered the impact of metabolites and degradation products on SAR prediction.

Certain chemical structures may be correlated with solubility in water or fatty tissues and these correlations, taken together with other data may permit regulatory estimation of exposure to aquatic organisms. The chemical compounds emphasized in the environmental research effort may be selected based upon their predicted hazard and extent of manufacture. Research will proceed by comparing SAR model predictions with defined sets of field data to estimate the SAR models' accuracy.

EPA's health effects research on SAR has two main objectives. First, to investigate the application of pattern recognition, statistical and thermodynamic techniques in combination to predict genetic, carcinogenic, and other toxic activities. Second, to construct chemical data bases and relate chemical structures to potential effects including genetic, carcinogenic, and eventually neurotoxic and reproductive effects.

Major planned research products include:

- Develop models to predict thermodynamic properties of chemicals to be used in estimating reactivity in the atmosphere, 1985
- Develop preliminary model for predicting toxicity to terrestrial plants and animals, 1985
- Evaluate SAR methods to estimate acute and chronic toxicity to aquatic organisms, 1985
- Evaluation of molecular electrostatic interactions to evaluate chemical toxicity, 1986
- Evaluate SAR pattern recognition techniques for predicting genotoxic effects with yeast and bacteria, 1986
- Report on molecular electrostratic interaction/structure-activity relationship methods for one class of chemicals to predict carcinogenic and mutagenic effects, 1986
- Report on SAR method development to estimate reproductive/teratogenic activities, 1988

Biotechnology: What health and environmental research is needed to support assessment and regulation of (1) biological control agents or (2) genetically engineered organisms?

In its broadest meaning, biotechnology is the application of biological sciences for the production of chemicals or life forms which have potential commercial uses. Basic research has provided researchers with the ability to manipulate genetic material (i.e., produce recombinant DNA-DNA *in vitro*) resulting in the rapid and relatively simple production of organisms with heritable characteristics selected by the researcher.

Under FIFRA the Agency has regulated biological material used for pesticide purposes for over a decade. These guidelines have recently been revised (Section 158 subpart). OPTS was recently advised it had the jurisdiction to regulate genetically engineered substances under TSCA. OPTS has recently received two inquiries regarding whether products of biological processes are subject to Premanufacture Notification (PMN) application. Futhermore, it is expected that such activities will be increasing.

To be able to make regulatory decisions required under TSCA, OPTS must be able to weight potential hazards with potential benefits of biotechnological processes. Research is needed in DNA and genetic engineering risk assessments, monitoring methodology, methods to define and characterize products, and development of criteria for regulatory use.

There are a number of other agencies, universities and private laboratories conducting research on genetic engineering and other forms of biotechnology. The National Institutes of Health have focussed specifically on problems associated with RDNA and on methods to design vector plasmids and organisms to reduce potential hazards. Their efforts, and others by the FDA in drug related research and the USDA on Agriculture applications, will be used by EPA in developing regulatory approaches. However, problems and challenges remain. To address these, the agency is contemplating a major research program. In order to protect the public health and environment from adverse effects of manmade exotic organisms and their by-products, the EPA will conduct research designed to understand the implications of, and to regulate as necessary, the expected increase in biological wastes from increased use of biotechnological processes. The agency's research will also explore biotechnology to reduce wastes and degrade existing problem compounds and improve EPA's ability to monitor biotechnology for health and environmental risks. Such research will also support state and local regulatory actions.

Initial EPA research efforts in biotechnology will determine the current limits of performing risk/benefit analyses to evaluate genetically engineered microorganisms prior to their introduction into commerce. Other EPA studies will develop methods to identify and assess the effects of biotechnology microorganisms in non-target organisms such as desireable aquatic and terrestrial species. Such research will include location and emission rates of the organisms, persistence, dispersion of organisms in the environment and resultant exposure and risk of infecting humans or the environment. We will begin to develop biotechnology - oncogenesis transformations models, and models for assessing biotechnology health impacts. We will also conduct technology and engineering assessments of physical, chemical and biological techniques and devices to contain and destroy those unwanted biological control agents or genetically engineered organisms. Other EPA research efforts will investigate the survival, transport and fate of recombinant organisms, and will develop test methods using RDNA or monoclonal antibody techniques for assessing health and environmental hazards to fish and avian species. Simultaneous with launching this research, EPA will sponsor a series of workshops where experts can assess the state of knowledge and research needs associated with recombinant DNA public health risks, environmental risks, and the application of biotechnology to environmental problems.

Since 1975, EPA has been conducting research into the immunological effects of biological pesticides on mammalian cells. This research is intended to determine if biological pesticide agents can provoke immune responses and replicate in the mammalian systems. Efforts to date have focused primarily on baculoviruses.

Significant deficiencies currently exist in our ability to adequately deal with biological agents in a regulatory setting. For example, we lack the ability to precisely identify and quantify biological pesticide samples. Many problems stem from the fact that microbes are living organisms which undergo morphological and biochemical changes while in host species. Standardized methods for the isolation of these organisms from animal tissues are generally not available. Our future research will address the problem of isolating and identifying baculoviruses, bacteria, fungi, and protozoa from animal cells.

In order to determine how biological pesticides behave in the environment, our researchers will use methods developed for detecting, testing and/or measuring exposure under field conditions. As in other parts of the toxic substances and pesticides research program, the correlation of laboratory results with field data will provide the essential validation of screening systems. If appropriate, exposure-dose-response data and other mathematical relationships will be used to facilitate comparison and correlation.

Major planned research products include:

- Develop and test selected tier one protocols (screening) for estimating hazards to non-target terrestrial species. Emphasize dosing regimes, non-target endpoints, and survival and persistence of biological control agents (BCAs) in the environment, 1984
- Report on viral effects on mammalian immune responses in cells, 1984
- Report on use of monoclonal antibodies for identification of biological control agents, 1984
- Report on the mechanisms of persistence of baculovirus in tissue, 1984

- Report on the development of DNA nucleic acid probes specific for biological pesticide agents, 1985
- Conduct *in situ* testing of *Bacillus thuringiensis* with non-target freshwater organisms under field conditions, 1985
- Conduct technology and engineering assessment of the potential for environmental contamination, and physical, chemical and biological techniques and devices to contain and destroy those unwanted biological control agents or genetically engineered organisms, 1985

Release and Exposure of Chemicals: What engineering research is needed to develop predictive capabilities in assessing release and exposure of chemicals into the environment, and determine best control measures to mitigate these releases and exposures?

Predictive capabilities in assessing release and exposure of chemicals into the environment are needed by EPA in the review of premanufacturing notices for new chemicals as required by TSCA. EPA plans to develop predictive models which will address different chemical unit operations, unit processes, and physical/chemical properties of chemicals and predict potential exposure and release levels as well as best control measures to mitigate release and exposure of new chemicals.

In 1984, EPA scientists will search for existing literature and develop an engineering research work plan for 1985 and after. During 1984, a pilot-scale test for the treatability of classes of potentially toxic chemicals will be conducted to build up a data base which will be utilized to validate these predictive models for waste streams.

Major planned research products include:

- Report on the release and exposure from unit operations, unit processes, and sampling activities 1985
- Evaluation of the techniques and devices to contain and destroy genetically engineered organisms, 1985
- Report on predicting the effectiveness of chemical protective clothing, 1985
- Determination of the fate of and other substances in wastewater treatment systems, 1985

Long Term Trends

The major long-term (to the year 2,000) trends in environmental research will be shaped by six rapidly developing areas of scientific knowledge: quantification of risk (including engineering predictive capabilities), structure-activity relationships, measurement technology biorationals and genetic engineering, human biological systems, and sensitive populations. While other areas are important, and scientific breakthroughs can skew trends unexpectedly, these are the most important forces currently identifiable.

The *quantification of risk* is the key to providing scientifically valid input into the risk management process. As more sensitive measurement capabilities highlight the long-term, low-dose exposure of more people to more substances, the process of environmental regulation will become ever more explicitly one of balancing conflicting goals and risks. This, combined with the dramatic increases in data- and model- handling capabilities of the next generation of computers will help to focus research on such data gaps as the effects of exposure to multiple pollutants, pollutant impacts on natural health recovery systems, neurobehavioral effects, ecosystem "robustness," etc.

Engineering predictive capabilities in assessing the release and exposure of new chemicals are urgently needed for the on-going PMN review activities. The number of new chemicals produced is rapidly increasing, which multiplies the complexity of the ways these chemicals release and expose to the environment. Models to predict the movement of these new chemicals will have to be improved and modified in order to meet the challenges posed by these new species of chemicals continuously propagated. The control measures to mitigate the release and exposure of new chemicals will be determined based on engineering feasibility, cost effectiveness, and energy efficacy. Those control measures will need constant verification and refinement to meet the ever changing needs.

Structure-activity relationships (SAR) (how a substance's chemical structure determines its environmental/biological activity) can be used as an indicator or guide to the necessity of further laboratory tests. A major advance in SAR research will result from the application of sophisticated computer science and the incorporation of biophysical data and research on the mechanisms of toxicity. Information now being developed on cellular and organismal processes such as absorption, distribution, metabolism, toxification, and excretion after exposure of the chemical to the test organism and the eventual biological effect will greatly enhance the predictive ability of SAR techniques. For example, one area where research could vastly improve SAR utility is in determining the behavioral and neurophysiological consequences of chemical and structural damage to the nervous system. Other influences include less data-intensive mathematical models and increased information on the relationship of chemical structure to the basic mechanisms involved in teratology and reproduction.

Measurement technology is just beginning to give us the capacity to measure: actual human exposures to a number of man-made chemicals, low concentrations of toxic substances and small amounts of individual chemicals within complex matrices (e.g., soil). Practical technologies to measure many non-volatile substances can be expected soon. Such developments may well outstrip our scientific capacity to determine the human health or environmental implications of exposure to such substances. This, in turn, could influence the focus of our research over the next 15 years.

Biorationals and genetic engineering will have many impacts which are very difficult to foresee at present. Two which can be seen are the development of ever more pest-specific chemical control agents and the production of living substances "designed" to fill a useful, man-made ecological niche (e.g., digesting and metabolizing dioxins). The former (precisely targeted control chemicals) will pose an unusual challenge in that they are so specific that tests on like organisms may not be relevant, and the environmental and metabolic "daughters" of such substances may be difficult to predict. The latter (genetically engineered "organisms") may be equally difficult to test for "safety", in some cases, because of the complexity and unpredictability of living systems. On the other hand, the environmental applications of both biorationals and genetic engineering hold enormous potential for obviating the need for broadcasting toxins and for solving existing environmental problems by detoxifying wastes.

Our understanding of *human biological systems* is yielding major insights which will dramatically alter future research focus. For example, neuroscience is rapidly developing. We are making progress towards understanding the cellular and biochemical events which control behavior of the whole organism. Advances in our understanding of the intracellular events and neurophysiological processes may fundamentally alter our evaluation of the neurotoxicity of substances. In other areas, new tests for biological effects are being perfected, advances are being made in our ability to study human tissue in the laboratory, oncogene research has isolated human DNA fragments which cause malignancies in mouse cells, and so on. Each new discovery at this level of detail provides another piece of the mosaic, and a picture of how humans function and respond to their environment is gradually emerging. The nature of this picture will determine future environmental regulatory strategies.

A growing awareness of how *sensitive populations* (categories of individuals, such as the aged and those with lung diseases, which show exceptional responses to exposure to environmental agents) differ from the norm will shape efforts to protect these individuals. Standards and tests designed with young, healthy individuals in mind may not be appropriate for the adequate protection of those who need protection most. The entire topic comprises a significant gap in current knowledge, and the research and regulatory implications of filling that gap are largely unknown.

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Long Term Trends

4 Hazardous Wastes

Introduction

Hazardous wastes and their impact on human health and the environment remain a major public issue. Hazardous wastes from industrial production have been common for decades. The legislation and research to address the problems they create have been launched. Because mitigation of the toxicity, resistance to treatment, and other characteristics of hazardous wastes are more complex than they are with conventional wastes, new information and improved technology are required to ensure that these wastes are safely handled and disposed.

Hazardous wastes include many man-made compounds which do not occur naturally. Little is known with regard to their potential toxicity or carcinogenicity. Many compounds are either slow to biodegrade or do not biodegrade at all. Moreover, the existence and extent of the health and environmental problems caused by hazardous wastes remain undefined. Such questions as concentrations at which chemical wastes cause adverse effects, routes of hazardous waste exposure and the effects of chronic exposure on people and the environment are only beginning to be explored.

In response to these issues and Congress' mandate, EPA has established a hazardous waste research program. The goal of this program is to reduce risks to public health and the environment by ensuring sound management of hazardous wastes.

The EPA research program for hazardous waste in fiscal year 1984 is allocated $32.5 million. These resources are distributed among the research disciplines as follows: engineering and technology, 50%; monitoring systems and quality assurance, 25%; environmental processes and effects, 16%; scientific assessment, 6%; and health effects, 3%.

Legislative Mandate

EPA's mandate for hazardous waste research comes from the Resource Conservation and Recovery Act (RCRA) of 1976, as amended; the Federal Water Pollution Control Act (FWPCA), as amended; and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. RCRA is the vehicle for defining, at the national level, the minimal guidelines and requirements necessary to protect human health and the environment from hazards posed by the treatment, storage or disposal of hazardous wastes.

RCRA also gives the EPA authority to establish national standards to ensure proper management, transportation, treatment, storage, and disposal of hazardous wastes. RCRA requires EPA to develop lists and criteria for determining what constitutes a hazardous waste, standards that have to be met by handlers of hazardous wastes, technical standards for issuing permits to hazardous waste filities and requirements for the authorization of state hazardous waste programs.

The Federal Water Pollution Control Act, which sets federal policy regarding the discharge of oil or hazardous substances into U.S. navigable waters, directs EPA to develop, promulgate and revise regulations pertaining to such discharges. FWPCA authorizes EPA to initiate civil action for violations and to undertake actions to mitigate damage to public health or welfare caused by discharges. Although regulations implementing FWPCA already exist, they require periodic updating based on new information and improvements in control technology.

The Comprehensive Environmental Response, Compensation, and Liability Act provides authority for a federal response to the release or threatened release of hazardous substances. CERCLA also includes the Post-Closure Liability Trust Fund. As a means to achieve its goals, CERCLA established the Hazardous Substance Response Trust Fund, also known as Superfund. While a significant amount of scientific activity is underway relating to Superfund activities, this activity is of a technical support nature and therefore is not appropriate for inclusion in the *Research Outlook*. Many of the results from the research described below, however, will be of use at some point in the Superfund effort.

Background

Wastes at industry sources or already in disposal sites need to be identified, characterized and classified as to their composition, quantities, and potential health effects. Existing and emerging treatment technologies should be evaluated and developed to provide alternate ways to detoxify these wastes. Sites to be used for disposal, and disposal technology to be employed at the sites, need to be evaluated to assure that they are effective. Discarded wastes need to be adequately monitored to ensure that hazardous substances do not escape into natural environments. Permits for operating sites and for disposing of wastes need to provide permittees with the appropriate requirements to be followed. Instrumentation to monitor sites and to assure compliance or to detect and measure problems needs to be effective for various types of wastes.

All of these activities and requirements demand a solid scientific base of technically sound, field-tested and proven procedures that supply accurate and timely information for solving a specific hazardous waste problem. Moreover, the data and information on which decision-making is based must be of high quality to assure consistent management or control approaches, since much of the regulatory authority for dealing with hazardous wastes will be transferred to state agencies. States will need monitoring methods for obtaining verifiable data. A Hazardous Waste Land Treatment Research Plan has been formulated by a peer panel of experts representing academia, industry, state, and consultants. This plan identifies seven major areas in which research and development efforts are needed. These areas are: (1) assimilative capacity, (2) monitoring/analytical methods, (3) closure/postclosure methodology, (4) verification of predictive design, (5) pretreatment options, (6) economics, and (7) technology transfer and technical assistance. EPA's research efforts will focus on these seven major areas of need.

A major problem facing EPA is the relatively recent recognition of the dangers from waste and the dearth of scientific data on the subject. For example, scientific analytical methods have been developed for many volatile and semi-volatile compounds, but less progress has been made in developing methods for non-volatile compounds. EPA's research program is designed to fill major information gaps, both to provide near-term solutions and to establish a scientific base for the longer-term. Consideration is given to a range of treatment options and their costs to enable cost-effective assessments of available alternatives.

Major Research Topics

Securing landfills and surface impoundments: What designs and operations would make landfills and surface impoundments more secure?

Landfills and surface impoundments have been used for years as an inexpensive means of disposing of hazardous wastes. The design of many of these sites followed haphazard, conflicting and sometimes erroneous information. Some of the problems of today, particularly ground-water contamination, are testimony to the inadequacy of the earlier approach. With that legacy in mind, one of the objectives of EPA's proposed research program is to develop the information needed to assure that landfills and surface impoundments are designed to be secure. The research focus is on the life span and efficacy of flexible, synthetic membranes and/or impervious soils used as liners for landfills and surface impoundments.

Flexible membrane liners (FML's) and impervious soils can be placed on the bottom of a waste site before the hazardous waste disposal begins; they can also be used to cap sites once they are filled. The liners, if installed and maintained correctly, contain wastes and isolate them from surface or ground water. The key design criterion for using FML's and impervious soils is whether they are compatible with the wastes they are to control: some wastes may pass through certain materials used in liners, other wastes may chemically degrade liners. EPA research projects are developing and evaluating compatibility test procedures for both synthetic liners and clay soil liners so that the waste management facilities can evaluate their wastes against alternative liners. Research projects are also investigating techniques to monitor the integrity of liners.

EPA has the leading role in federally sponsored FML research, although there are a few other organizations conducting their own programs. A small program conducted by the U.S. Army Corps of Engineers is looking at liner compatibility with military wastes (e.g., explosives). Private companies are developing new liners, but their product designs are hampered by the lack of precise descriptions of the specific waste mixtures which would require liners.

EPA's research approach is to develop tests to determine the compatibility of liners with various classes of organic and inorganic compounds at concentrations likely to be seen in waste mixtures. The tests will be for effects on porosity, permeability, and the response of the liners to chemical and mechanical stress. Installation of liners for waste management facilities present special types of problems. EPA has a research program to develop acceptable criteria for use in evaluating seaming FML's in the factory and in the field. The program will also develop criteria to ensure that the "as built" matches the "as designed" specifications for both synthetic liners and clay soil liners.

A method will be devised to predict likely leachate compositions based on various concentrations of waste compounds and chemical reactions among them. The liners will then be installed in test beds and evaluated under actual field operating conditions. Monitoring and measuring equipment will be developed to determine the durability of the liners and their ability to contain and control specific waste mixtures. The output of the research will be a set of recommendations for using liners at waste sites.

Research regarding surface impoundment liners will also focus on detecting leaks in liners. New methods and instrumentation are needed to detect leaks. The current method is to take periodic samples from monitoring wells around an impoundment. Research is evaluating acoustic emissions monitoring, time domain reflectometry and electrical resistivity methods for detecting leaks in liners. The objective is to detect leaks at the liner — before the pollutants reach the ground water. Research tests at a pilot scale pond lined with an FML having known leaks will be followed by limited field evaluations. Once a leak has been detected, however, methods are needed to plug it. Techniques are being evaluated for determining the repairability of leaking liners under a variety of conditions.

A manual with landfill and surface impoundment design recommendations was made available in 1983. It will be updated periodically as more is learned about waste characteristics and liner compatibility. The leak-sealing methods will be investigated in 1984. In future years, emphasis will be put on evaluating technologies to increase service life and to improve the integrity of the installed liner systems.

Other means to control the flow of waste-site leachate will be studied to match the type of control methods with the nature of the leachate problem and the characteristics of the waste site. This work is important because groundwater and surface water will become contaminated as they come into contact with the leachate plume. This, in turn, will affect drinking water aquifers and could, depending on the seriousness of the contamination, lead to the closure of drinking water sources.

An interim protocol has been developed to provide a guide to the efficiency of applying various wastes in a land treatment system. The laboratory phase includes soil and waste characterization, microbial activity, principle hazardous organics reduction, toxicity reduction, leachability, adsorption, respirometry, phytotoxicity, and microtoxicity evaluation. This phased approach defines significant soil parameters, identifies and quantifies hazardous constituents contained in the waste, as well as categorizing the treatability potential of a specific waste when applied to a specific site. If the laboratory phase indicates the waste is a potential candidate for land treatment, then the pilot scale evaluation is initiated to provide information relevant to actual climatic conditions. EPA's Office of Research and Development currently has a 100 acre pilot plant available for land treatment evaluation of various industrial hazardous wastes.

At the pilot scale land treatment system, individual plots will be established and characterized for biological, physical, and chemical parameters. Various loading rates, which are based on laboratory evaluations, will be established in triplicate on the plots. The established plots will be optimally managed using current state-of-the-art technology relating to application, incorporation, carbon:nitrogen: phosphorus ratio, pH, oxygen, and moisture content. Samples from the zone of incorporation will determine biological degradation, immobilization, and chemical transformation; core and soil pore samples will be obtained from the unsaturated zone to determine any pollutant migration; surface runoff samples will be analyzed to identify any pollutants which might be present during rainfall; air samples will be obtained to identify any organic components which might volatilize due to temperature/moisture conditions, and groundwater monitoring will be established for background and monitoring information.

Major planned research products include:

- Procedures for determining leachate composition, 1984
- Standardized test procedures for determining waste/liner chemical compatibility, 1985
- Procedures for locating and repairing liner leaks, 1986

Land treatment: What information is needed to make optimum use of land treatment for hazardous waste disposal?

The concept of land treatment for hazardous wastes is not new. Petroleum companies have used the technique for more than 20 years with good success in treating substances such as tank bottom residues. EPA's research will build upon the information garnered from these earlier successes and will extend the land treatment option for a broader range of hazardous wastes for which conventional disposal is economically and environmentally undesirable. Research will focus on understanding the subsurface physical, chemical and biological processes that affect the movement and degradation of wastes.

The key to optimal use of land treatment systems for hazardous waste disposal is a sufficient understanding of the behavior of pollutants in the subsurface environment. Only through elucidation of the importance and magnitude of the various physical, chemical and biological mechanisms functioning in the subsurface will we be able to integrate the influence of these processes and understand pollutant behavior in this media. Consideration of this information in site selection, plant layout, loading rates, incorporation methods, etc. will allow for appropriate environmental safeguards during all phases of land treatment operations. Proper management includes laboratory evaluation of the applied waste and receiving soil plus application, monitoring and data evaluation. The major benefits of using this natural assimilative capacity of soil are two-fold: first, it can be a very cost-effective approach, and second, through land treatment such processes as biological degradation, chemical transformation and immobilization can convert some wastes into innocuous compounds rather than having them stored in a hazardous form in landfills and surface impoundments.

Land treatment studies begin in the laboratory, then move to a greenhouse environment and, finally, to actual test sites if good treatability potential is indicated. EPA currently has a test area of more than 100 acres available for land treatment studies. Laboratory tests will be made of actual waste mixtures supplied by cooperating industries. The mixtures will be characterized to determine the amounts and types of waste compounds they contain. The land at the test sites will be characterized to determine its physical and chemical parameters and likely biological responses to the waste. The mixture will then be spread on the soil and tilled.

Measuring and monitoring instruments and sample taking will reveal the degree of biological activity taking place. Soil column testing in the laboratory will determine the migration and degradation of pollutants and allow for the calculation of loading rates. Variables will be evaluated to determine the optimum land treatment process. The effect of such variables as loading rate of waste initially applied to the land, different application and incorporation methods, amount of soil moisture, pH, and soil fertility on subsurface process kenetics will be determined so that the degradation potential of various wastes under various soil and climatic conditions can be more accurately predicted.

Volatile organics: How can air pollution from volatile organics be controlled?

Waste materials which are disposed of in a landfill or surface impoundment; treated to change their chemical or physical composition; or stored in tanks, piles, or uncovered may produce air pollution when either the materials themselves, or the products of chemical reactions among them, volatilize (evaporate). Such volatile organic compound (VOC) emissions found in the air around treatment, storage and disposal facilities may produce health and environmental effects as well as unpleasant odors.

EPA's research program is developing techniques for measuring and predicting the amounts and rates of VOC emissions from surface impoundments, land treatment facilities, landfills, and storage facilities. Methods are being developed to estimate VOC movement through different media and to predict emissions from different surfaces. Various methods for sampling of gases emitted from surface soil will be examined, and selected methods will be applied in field evaluations. These sampling techniques for measuring gaseous emissions in the soil column and at the surface will be developed and evaluated to estimate vapors emitted to the ambient air. In 1984, EPA will field test an automated cryogenic trapping and analysis system for sampling and analyzing toxic air pollutants. This sytem will provide monitoring data approximating a real-time response.

Research projects will develop and refine air-emission release rate models and verify these models via field monitoring. Field monitoring will also develop a data base on the amounts and rates of VOC emissions from actual hazardous waste facilities. Information comparing field sampling results and estimated emissions from models will be available in 1984. Statistical comparisons of the emissions rates will be made.

VOC emission control technologies which can be applied to treatment, storage and disposal facilities will be investigated. Laboratory and pilot scale studies on emission from surface impoundments will be a primary area of study along with examining pretreatment techniques to remove volatile compounds from wastes prior to disposal or impoundment. Results will be available in 1986.

Selected VOC emission controls for other treatment and disposal processes will be evaluated in the field to document their cost-effectiveness. These will include the use of covers and associated VOC destruction/capture technologies for tanks and lagoons capping of landfills, and maintenance programs to cut fugitive emissions. The verified prediction and measurement methods will be used to evaluate the magnitude of the VOC problem so that site designers and permit reviewers can compare performance estimates with actual emissions. This evaluation and comparison will provide the technical basis for potential regulatory action and for identifying future research needs.

Major planned research products include:

- VOC emission measurements from hazardous waste treatment, storage, and disposal facilities, 1984
- Predictive modelling and measurement techniques for VOC emissions from surface impoundments and land disposal facilities, 1984
- Assessment of air emissions from land treatment of refinery oily sludges, 1984
- Soil-gas sampling techniques of chemicals for exposure assessment, 1986
- Assessment of alternative control technologies for VOC emissions, 1986

Incineration: What information is needed to optimize the incineration of hazardous wastes?

Incineration is an effective method for destroying hazardous wastes. Its use in the past was limited by its relatively high cost when compared to landfill and surface impoundment alternatives. However, these alternatives are now becoming more expensive and less available for certain wastes and geographical regions. There are currently more than 300 hazardous waste incineration facilities in the United States.

Extensive incinerator performance data have been developed in support of RCRA regulations, regulatory impact analyses, and regional and state-level permit programs. An understanding of the overall destruction efficiency capability of these systems is emerging from analysis of these data. However, such information is insufficient to enable prediction, real-time measurement, and optimization of incinerator operation. EPA research will develop the scientific and operating data needed to assure compliance and safe operation of thermal destruction systems.

Ongoing efforts will assess the performance capabilities of existing hazardous waste thermal destruction devices (incinerators, industrial kilns, boilers, etc.). Resultant data will provide the technical foundation for agency policies and regulations with respect to thermal destruction as a hazardous waste disposal option. This research involves, for example, the testing in the field of present full-scale devices to assess the degree to which they can meet initial RCRA requirements of 99.99 percent destruction effectiveness for incinerators. Such tests not only provide the required data base on current capabilities to attain the EPA's initial regulatory goals, but also provide the baseline information on cost vs. performance essential for formulating objectives and associated priorities in the whole hazardous waste area (e.g., for what compounds are health effects or transport/fate studies needed, what kinds of monitoring systems and ambient measurement methods are required, how much emphasis is needed on alternative treatment technologies).

Research underway at the EPA Combustion Research Facility in Arkansas and at the EPA Center Hill research facility in Cincinnati is developing an understanding of thermal destruction chemistry and of the engineering of thermal processes. This data is a first step in characterizing and assessing the performance of full-scale thermal destruction devices from a minimum set of evaluative tests and in extrapolating performance information from one waste type to another or from one scale or type of equipment to another so that small-scale test burns can reliably be used in permitting decisions.

This research involves the use of a combined theoretical/experimental approach to relate the products and kinetics of the various physical and chemical steps and reactions of the incineration process (atomization, volatilization, pyrolysis, oxidation, dehalogenation) to such parameters as waste composition and form, feed nozzle design, temperature and oxygen profiles, integrated dwell times, mixing and combustion chamber geometry. Theoretical models of combustion processes will be employed to design and interpret the results of parametric experiments. This research also involves establishing a sound basis for predicting the relative "incinerability" of various hazardous waste constituents and will identify the waste components and associated thermal environments which should be avoided to prevent the formation of toxic by-products.

Laboratory and limited field evaluation of stack-gas sampling trains for volatile organics will be undertaken, and sample preparation and methodologies updated. The revised method will be field tested at a hazardous waste incinerator in 1985. In addition, a stack sampling train for semi-volatile organics will be evaluated and the revised method validated in 1985. The validated methods are needed for measuring the volatile organic compounds (VOC) content of the waste incineration stock gas in order to determine the destruction and removal efficiency of substances being incinerated. The issuance of operating permits are based on such measurements. Products will include evaluation and standardization of the Volatile Organic Sampling Train (VOST) and semi-VOST methods for VOC measurement in 1985.

A further goal of EPA's research is to define easily monitored incinerator facility operating parameters (e.g., rates of carbon monoxide to total unburned hydrocarbons, CO/CO2 ratio, etc.) which correlate with system performance so as to allow rapid, reliable, and economical determination by enforcement officials of compliance with permit conditions. This will enable determination of preventive or corrective actions necesary to avoid uncontrolled excursions from permit conditions. This research will involve, for example, the examination of transient conditions which can occur during startup, shutdown, occurence of waste composition anomalies and mechanical failures. Such conditions can cause the incinerator to fail with respect to the attainment of required performance or can result in the formation of toxic by-products.

In addition to these studies of conventional incineration processes, a research program will also investigate the performance capabilities of innovative thermal destruction processes. This research will involve, for example, the development and evaluation of process improvements or innovative thermal technologies (both destruction/detoxification and, perhaps, resource recovery techniques), which are capable of handling hazardous wastes not suitable for current systems, which are more cost-effective than current systems, or which are capable of attaining higher or more reliable performance than existing processes. Major planned outputs include reports of performance evaluations of molten salt reactors, high-temperature electromagnetic furnaces, plasma torch reactor and catalytic wet air oxidation.

Detoxification of intransigent toxins: How can difficult to destroy and/or highly toxic wastes be safely detoxified at a reasonable cost?

Detoxification of wastes can be a very costly process if the wastes are dilute, resistant to chemical or physical degradation, located a great distance from the treatment or disposal site, or have little recoverable value. Some wastes can be safely detoxified via high temperature processes such as industrial boilers or cement kilns. In such cases the fuel value of the waste can also be recovered, lowering the cost of disposal.

Contaminated soils, however, present a much more difficult problem. Excavating and transporting large amounts of soil is expensive, and recovery of any value from the contaminants is unlikely. Thus, in-situ detoxification, if practicable, would be an alternate to off-site disposal.

In-situ detoxification requires a considerable amount of time to allow chemical or biological species to saturate the contaminated area, contact the pollutants, and transform the material to harmless substances. During this time, the further migration of toxic chemicals must be controlled and the area appropriately quarantined. The lateral movement of contaminants in soils can be controlled through the use of hydraulic "walls" or trenches and wells which inject or withdraw water at key points of the subsurface flow pattern. Vertical migration of pollutants is generally a slower process and may be less critical in the absence of a shallow aquifer or in the presence of an impervious layer of clay or rock.

EPA's planned research includes the determination of effective solvent-reagent formulations for chemical treatment of toxic wastes and the modification of organisms and methods to promote biological degradation of contaminants. Such procedures may some day eliminate the need for expensive excavation and hauling of bulk hazardous waste contaminated material. Projects planned include evaluation of polyethylene glycol-based reagents and the development of new strains of yeast cells for the treatment of dioxin contaminated soils.

Selective removal: Can innovative treatment techniques be used to selectively remove the toxic constituents of both liquid and gaseous waste streams?

The identification of specific toxic components within a waste stream generally reveals small amounts of toxic substances diluted by much larger amounts of usually innocuous material. Processes such as incineration, biodegradation and landfilling have capital and operating costs related to the *total* amount of material requiring treatment or disposal, not the amount of pollutant in the material itself. Separation or concentration of the toxic constituents of a waste stream can influence the feasibility and economy of applying a particular disposal method to that waste stream.

Historically, wastes have been subjected to gravity settling, filtration, chemical precipitation, adsorption, biological oxidation, etc. As waste treatment techniques become more sophisticated to meet the increasingly stringent mandate for control of pollutants, innovative extraction technology is being evaluated, e.g., supercritical CO_2, to allow the selective removal of particular chemicals from waste streams. Once removed from the waste stream, the substances may be recovered or destroyed by appropriate methods.

The manipulation of living organisms to remove or destroy toxic components of wastes could greatly expand the options available for the ultimate disposal of the vast bulk of biological treatment process effluents and sludges. Genetic engineering is being utilized in an effort (long-term) to transfer the ability to degrade toxic substances to hardy, common strains of organisms which predominate in the complex populations found in waste treatment processes. In order to be fully effective, the organisms should preferentially absorb and/or assimilate the toxic components of wastes while ignoring the abundant non-toxic constituents. EPA's research is investigating naturally occurring and artifically transformed organisms, including pseudomonas and yeasts, to determine their potential utility. Techniques being utilized include recombinant DNA and plasma-assisted molecular breeding.

Sampling analysis and field monitoring: How can sampling and analysis methods be improved?

Some of the current state-of-the-art methods for analyzing hazardous wastes and waste site samples have not undergone the rigorous evaluation necessary to define standard confidence limits for the data they produce. Such limits, stated as the "plus-or-minus" confidence limit of each data point, are especially important when the measured concentration is near the regulatory decision limit used to determine whether a waste is hazardous or a site sample indicates a health or environmental problem.

Current programs use analytical methods based on technology developed for EPA's water monitoring programs. Confidence limits of these methods can now be applied to the analysis of aqueous samples. However, only limited information is available for their application to hazardous waste samples and samples from waste sites (e.g., soils, sediments and solids). An extensive program to validate these methods, where appropriate, is being undertaken. This will take a number of years since there are over a hundred methods to be evaluated and others are being added. Once validated, the methods will appear in the Federal Register.

Because of this limitation, EPA has placed a high priority on developing quality assurance information on various methods. A data base will be developed consisting of standard reference materials containing priority pollutants. This will serve as a single, traceable source of known purity standards for RCRA monitoring activities.

EPA researchers are also evaluating new technology and developing improved quality control and assurance procedures to reduce the cost of analyses while simultaneously narrowing the confidence limits of the resulting data. Guidance documents will be produced that define the confidence limits of the current methodology and describe improved protocols and technology. Finally, standardized methods will help to support specific RCRA regulatory requirements such as methods for characterizing waste as hazardous due to toxicity, corrosiveness, ignitability, etc.

One EPA study will improve the current extraction procedure for the RCRA toxicity characteristics which is good, primarily, for inorganics. The procedure now in use can only be applied to a small list of toxic materials and does not yield an extract that is amenable to bioassay. The improved procedure, should yield an extract suitable for bioassay and appropriate for organic materials also. The procedure is being evaluated to determine its reproducibility and how well it reflects actual waste disposal situations. A report on the results of this procedure is expected in 1984. Other research includes developing standard protocols for other RCRA characteristics such as ignitability (flash point), corrosiveness, and reactivity due to toxic gas generation. These protocols will undergo testing to establish their precision and accuracy during 1984 and 1985.

Another research effort is evaluating the use of bioassays for determining the toxicity of hazardous wastes. The Ames Test is in collaborative testing and a report will be available in 1984. The Daphnia magna bioassay will undergo collaborative testing in 1984. Other bioassays will be identified by the Office of Solid Waste and undergo similar protocol development and evaluation during 1984-1985.

The evaluation of methods to analyze hazardous wastes will continue. Collaborative testing of an analytical protocol for measuring medium concentrations (from one part per million to 100 parts per thousand toxics concentration) will be completed in 1984, and evaluation of methods to extract organic and inorganic samples (soxhlet vs. liquid-liquid extraction for organics; digestion procedures for inorganics) will be reported on in 1984. A specific analytical method for identifying and quantify dioxin in hazardous waste is being evaluated. Methods are required that detect dioxin at very low concentrations (100 parts per trillion), even in the presence of higher concentrations of other substances. An initial dioxin protocol will be provided during 1984. Efforts will then be initiated to provide similar protocols for dibenzofuran and another highly toxic compound by 1985. A low resolution RCRA method, not isomer specific, to measure total TCDD by GC/MS is being developed. The high resolution method to support the National Dioxin Strategy will measure parts per trillion in soil, sediment, and fish as well as 30 parts per quadrillion in water. The protocol will be developed in FY 1984.

Screening methods will be developed to reduce the burden of sample preparation and to yield qualitative information. The x-ray fluorescence method requires the least sample preparation, but yields only qualitative data. The triple quadrupole mass spectrometer (TQMS) can be used to rapidly analyze such pollutants as PCB's and to produce semi-quantitative data. The inductively coupled plasma spectrophotometer requires additional sample preparation but yields more information on the element content of the sample than atomic absorption spectrometry. Development of rapid screening methods of hazardous organic compounds in air near hazardous waste sites are being evaluated. One such method is the Tunable Atomic-Line Molecular Spectrometer (TALMS) and cryogenic Trapping with GC analysis to measure benzene.

Projects to improve the quality of hazardous waste data and reduce the cost of analysis are under way. One analysis method, known as pulsed positive ion negative ion chemical ionization mass spectroscopy, has the potential for improving the sensitivity of mass spectroscopic analysis of very toxic materials. The method is being evaluated and a protocol was produced in 1983. Tandem mass spectroscopy for the quick screening of hazardous wastes will be reported on in 1984. Fourier transform infrared spectroscopy is also being investigated for use in the analysis of high concentrations of hazardous waste. Fibre optics are being investigated to be used in geochemical measurements in bore hole investigations. Optrodes have been found to fluoresce when in contact with pollutants.

Major planned research products include:

- Portable TALMS for Benzene, 1984
- TQMS for analysis of Dyes and Orgonometallics Compounds, 1984
- Daphnia Magna Protocols, 1985

Screening complex wastes: How can complex wastes be screened to determine their hazard?

Section 3001 of RCRA requires EPA to promulgate criteria for identifying the characteristics of hazardous wastes and to provide a listing of hazardous wastes. Because of the large number of wastes to be screened, it may prove useful for the EPA to develop a battery of rapid, inexpensive bioassay prescreening tests that prioritize hazards from complex chemical mixtures by determining which wastes are most important for toxicological characterization. If the prescreening shows a waste to be potentially hazardous, then a second battery of confirmation screening tests may be used to determine affected health endpoints and the level of exposure at which effects can be observed. Results from this second screen will be used in the process of analyzing a waste for listing or delisting as a hazardous waste. Currently existing methods have not been validated for complex mixtures and not all endpoints have rapid, inexpensive test methods to quantify potential effects. Research will be conducted to develop such methods.

The determination of which testing procedures can be used to estimate relative degree of hazard is a major issue for determining health hazards from chemicals. The goal is to develop a group of tests that will allow estimates of relative hazard to be made at reasonable costs. EPA's approach to solving this problem is to validate shorter-term toxicological testing procedures for ranking hazards to human health. Currently that ranking is obtained by more conventional, but more expensive test procedures.

To predict the ranking of hazards to human health, it is necessary to identify two different types of toxicity: responses which result from genotoxic effects, on the one hand, and toxicity to target organs, on the other. In some cases substantial evidence indicates qualitative correlations between short-term and more conventional testing procedures. However, use of data from the short-term tests for quantitative estimates of health risk is not yet practical. EPA research projects will establish the cause-and-effect relationship between the short-term indicator of adverse health effects and overt diseases, and will determine the quantitative relationship between dose-response, the indicators, and the diseases. The first three years of the research will emphasize establishing empirical relationships between indicators and the production of diseases. Key goals of this work are the determination of which testing methods are clearly irrelevant to human health effects and the establishment of cause-and-effect relationships between indicator and disease for the final validation of health effects models.

By 1985, researchers will complete an evaluation of an inexpensive, qualitative prescreening protocol integrating existing methods for predicting biological activity (chronic toxicity, mutagenicity, neurotoxicity, etc.). The report will assess the efficiency of the protocol for application to RCRA materials such as complex mixtures of man-

ufacturing residues. The protocol is being developed to provide the data to support setting of first-level priorities using an integrated battery of tests. Also by 1985, initial field testing will be completed for an integrated protocol of a second-level, confirmatory battery of existing screening tests. The protocol will quantify levels of dose-response using a single set of test animals for the specific toxic hazards of carcinogenicity, mutagenicity, system toxicity, neurobehavior and teratogenicity. When proven, this protocol, by quantifying risks, could be used as a basis for determining if a waste is hazardous.

Major planned research products include:

- Determination of how well the confirmation screen correlates with the prescreen, 1985
- Final evaluation of a prescreen protocol, 1986
- Evaluation of the confirmation protocol for an integrated toxicological screen, 1986

Non-volatile compounds: How can non-volatile compounds be measured?

Current EPA monitoring methods are, to a large degree, applicable only to the volatile and semi-volatile compounds that can easily be analyzed by gas chromatography and GC/MS. Many potentially toxic compounds (e.g., larger molecular weight compounds) are not easily analyzed by the current protocols since they depend on compounds that volatilize, and thus are not amenable to gas chromatograph or GC/MS. While monitoring methods exist for some of the less volatile compounds — for example, liquid chromatograhpy (LC) can be used for some pesticides — current routine monitoring procedures cannot adequately analyze intractable compounds (those not easily removed from water or similar matrices) or non-volatile compounds. This is significant because there is a considerable proportion of non-volatiles in samples from some hazardous waste sites. EPA research will attempt to identify or develop analytical methods to measure these compounds.

A report on the detection limit of an LC/MS method for nine RCRA carboxylic acid herbicides in groundwater and EP extracts will be provided in 1985.

Two methods being studied are high pressure liquid chromatography and triple stage quadrupole mass spectroscopy. The mass spectroscopy method will be initially evaluated in 1983 for its application to non-volatile toxic chemicals. Pending the success of that evaluation, the method will be fully developed in 1985.

Data quality: How can the quality of sample data be assured?

Analyses of hazardous wastes are being conducted under the auspices of the EPA throughout the United States. Rigorously defined analytical protocols are required to assure that the laboratories conducting the analyses produce data of known quality. Quality assurance is needed to:

- develop/evaluate analytical standards for instrument calibration,
- develop/evaluate reference solutions for evaluations of laboratory performance,
- develop/evaluate reference materials (soils, sludges, etc.) of known composition for intercomparison studies,
- validate sampling, analytical and biological methods, and
- determine equivalency of new sampling, analytical and biological methods.

EPA is developing and applying analytical protocols that support both RCRA and CERCLA monitoring responsibilities.

A large number of EPA's published test methods have not been validated for matrices encountered in the hazardous waste scenario. These methods are needed to assure legally defensible test results. During validation, test methods will be evaluated by round robin laboratory testing. The generated data will be used to define the capability for these methods when they are used for routine monitoring. Four to six methods will be selected and tested by a single laboratory on a large number of waste samples. After refinement and revision of the protocols, those methods will be tested by seven to nine laboratories on a variety of waste samples. The data will be evaluated and precision and accuracy ranges established for each method tested.

Quality assurance is a key part of this work. EPA will also maintain a repository of calibration standards. This repository will support RCRA requirements, as will reference materials and solutions developed by EPA to evaluate laboratory performance and to ensure comparability of analytical data. We are obtaining and purifying all materials on the Appendix VIII list for eventual development of the calibration standards.

Long Term Trends

Due to the continuing focus of concern and resources on hazardous waste issues, this is one area where the knowledge base will grow rapidly over the next decade. In this section we discuss the scientific and research trends in three areas — monitoring, health effects, and control technology.

Trends in environmental *monitoring* will include major advances in methods for measuring intractable compounds, personal exposure monitoring, less expensive ground-water monitoring, in-line process monitoring, and predicting the degradation and transport of hazardous substances. For example, most polar compounds are extremely difficult to measure at low levels (low ppm to ppb range). Several of these compounds are either toxic or potential carcinogens. Over the next decade, we can expect analysis methods to be available which do not require such compounds to be in the gaseous phase.

Methods for determining *actual* human exposures will develop rapidly. Simple, reliable methodologies can be expected for personal monitoring for a wide variety of organic and inorganic species that are present in the environment. The availability of such techniques will dramatically improve our ability to perform better exposure and risk assessments.

Current methods of monitoring groundwater for hazardous wastes require excavation or well drilling and are very expensive. Development of remote sensing devices or probes that continuously monitor underground water would be extremely useful.

The number of samples from hazardous waste sites that need to be analyzed, and the complexity of the analyses, are growing geometrically if not logarithmically. Automation and the use of robotics in sample preparation and analysis will be an area of explosive growth. The handling of these samples is tedious, repetitious and potentially dangerous — an ideal application for robotics. Such applications will increase accuracy, reduce errors and cut the cost of analyzing specific samples by a large factor.

Methods for monitoring processes, especially those used to treat or destroy hazardous materials will receive more attention. Monitoring of low levels of organic compounds in incinerator stack gases by using in-line process monitors should produce a major advance in this area. More importantly monitoring of VOC's from area sources will be developed.

Lastly, many chemicals may be biologically or chemically transformed into compounds that are more toxic or mobile than the parent compounds. As a result, methods to monitor and predict the transformations and transport of chemicals in the environment will gain in importance.

Throughout the next decade, concern over human *health effects* will continue as new products and new chemical processes produce conditions of unknown toxicity and complex chemical mixtures raise untested toxicological risks. In response, research into molecular biology will yield ever more sensitive biological markers for the presence and onset of human toxicological diseases. Immunotoxicological sciences will take major strides in uncovering the mechanisms of host defense systems. Research can be expected to more sensitively define the specificity of toxic insult to target organ. And, both research and routine testing will develop a body of toxicological data which will vastly improve our confidence that the quantity of risk measured and the methods employed validly represent the human processes and the concomitant human risks predicted.

These developments will be applied, in the area of hazardous wastes health research, to improve testing protocols in toxicological screening batteries. The less sensitive tests will be replaced with tests using improved biological markers and more specific indications of the selectivity of toxicant to harm particular target organs. All of these developments will eventually lead to development of a battery of technologies and methods which can be rapidly applied under field conditions to determine the human health risks of specific environments or events.

There are three basic control approaches for hazardous wastes: waste reduction techniques which limit the *generation* and amount of hazardous wastes, destruction/detoxification technology which convert waste to harmless substances, and storage methods which keep them separate from the environment. It is becoming clear that the burial of untreated wastes is environmentally unacceptable.

Hazardous waste management in the next decade will undergo a sharp transition from reliance on land disposal to dependence on alternative treatment and disposal technologies. In the future, regulated wastes which are disposed of via land disposal may decrease significantly. By 1990, treatment and disposal processes that can detoxify or virtually destroy hazardous wastes are likely to be the rule. Innovative, chemical, biological, and thermal waste treatment approaches will greatly improve waste management technology by providing alternatives which are capable of handling wastes not suitable for existing systems and which are capable of achieving a higher degree of performance (% removal, reliability) more cost effectively. Processes such as high temperature slagging incinerators, chemical dechlorination processes, microbial degradation, and fixation and encapsulation processes, are among such innovative treatments.

In summary, by 1990, increasing regulatory and technological constraints will be applied to the use of conventional land disposal techniques for many types of hazardous waste. Research and development must be conducted to assure that technically feasible and economic alternative technologies are available for safely managing these wastes.

5 Air and Radiation

Air and Radiation

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Extrapolation modeling: How can EPA's risk assessment capabilities for air pollutants be improved through the use of extrapolation modeling?

Lung disease: What is the contribution of air pollution to the development of chronic lung disease?

Sensitive groups: What are the effects of acute exposures to air pollutants on sensitive population groups?

Cancer: What is the contribution of air pollution to lung cancer and other types of cancer?

Nonionizing radiation: What are the health effects associated with environmental exposures to nonionizing radiation at frequencies from 60 Hz. to $3x10^{11}$

Indoor air: To what extent do indoor sources and exposures to air pollutants contribute to health risk?

Human exposure: What monitoring capabilities will allow accurate determination of actual human exposure to air pollutants?

Hazardous pollutants: What technologies and data are necessary to identify and quantify hazardous air pollutants?

Models: What models best describe the regional, mesoscale, and urban scale transport and transformation of pollutants?

Complex terrain: How can air quality models reflect complex terrain conditions?

Pollutant fingerprints: Can sources of pollution be identified by the unique properties ("fingerprints") of their pollutants?

Crop and forest damage: What are the costs of damage to crops and forests from air pollution?

VOC, NO_x control: What are the most effective emissions reduction technologies for volatile organic compounds and nitrogen oxides?

Coal combustion pollution control: What air pollution control technologies promise improved cost-effectiveness for controlling pollutants from coal combustion?

Long Term Trends

5 Air and Radiation

Introduction

The Environmental Protection Agency's air pollution research is conducted through four major disciplines — environmental engineering studies to improve measurement and control of emissions from stationary and mobile sources — environmental processes and effects research to determine the fate, transport and transformation of atmospheric contaminants — monitoring and quality assurance studies to provide for the identification and measurement of contaminant levels — and health effects research to determine the human health impacts of air pollution.

This research program is oriented toward the agency's pollutant-specific regulatory requirements and is focused on five major types of pollutants and pollutant sources.

The **gases and particles** program is concerned with the health and environmental impact of sulfur oxides, particles, and lead.

The **oxidants** program studies nitrogen oxides, ozone, and ozone precursors, which are either directly emitted or formed as a result of atmospheric chemical reactions. Volatile organic compounds (VOC) are an important subset of these precursor chemicals.

The **hazardous air pollutants** program studies both pollutants which are listed by EPA as hazardous and others which may prove to be hazardous. This program also investigates hazardous and non-hazardous indoor air pollutants.

The **mobile sources** program produces scientific information needed for assessing the impacts of vehicular emissions. Major pollutants of interest are carbon monoxide (CO), diesel particles and unregulated organic emissions.

The **non-ionizing radiation** research program provides the scientific data, methodologies, and assessments required to determine the regulations necessary to ensure that exposure to non-ionizing radiation materials in the environment is within a safe range for the public.

The air research program for fiscal year 1984 is allocated $64.6 million. This total is divided among the research disciplines: environmental engineering 13%, environmental processes and effects 26%, monitoring and quality assurance 20%, health effects 32%, and scientific assessment 9%.

The cross-discipline category allocation is: gases and particulates 45%, oxidants 23%, hazardous air pollutants 20%, non-ionizing radiation 3%, and mobile sources 9%.

Legislative Mandate

The Clean Air Act (CAA), as amended in 1977, gives EPA the authority to set minimum standards for air quality. State and local governments are responsible for preventing and controlling pollution sufficiently to attain those standards. EPA's research role under CAA is to conduct research and development programs to acquire the information needed both to determine the need for, and to support, defensible air pollution standards and the associated regulations.

Background

To meet CAA requirements, EPA's air pollution research programs address two major tasks — gathering data on the currently regulated air pollutants in order to revise standards and implementation programs, as needed, on a periodic basis, and compiling data on unregulated pollutants to determine whether potential health and environmental risks may warrant future standards. In the first case, the research refines and extends existing findings. In the second, the research establishes and tests hypotheses. Data derived from both efforts will support the National Ambient Air Quality Standards (NAAQS), the New Source Performance Standards (NSPS), the National Emission Standards for Hazardous Air Pollutants (NESHAPs), the Prevention of Significant Deterioration (PSD), visibility protection and mobile source standards.

The results of research on certain air pollutants are compiled in "criteria documents" which are required by Section 108 of the CAA and which provide the scientific criteria upon which many regulatory decisions are based. Currently, criteria documents have been published for the pollutants regulated by NAAQS under Section 109 of the CAA. These pollutants are ozone, nitrogen dioxide, sulfur oxides, carbon monoxide, particulate matter, and lead — the "criteria pollutants."

Further research on criteria pollutants is performed to refine the knowledge base underlying the standards. For example, questions may include: Should the standards be higher or lower? Should different indicators for pollutants be devised (e.g., particles smaller than 10 microns)?

Research into potentially hazardous air pollutants (those regulated under Section 112 of the CAA) asks such fundamental questions as: What pollutants are of concern? How dangerous are they? In what concentrations? What are actual human exposures to these pollutants? Results from this research are published in health assessment documents.

Major themes cut across the air pollution research programs and the issues associated with them. For example, ambient air concentrations of a pollutant at a fixed point may not realistically represent the actual exposure that will determine adverse health effects. For some pollutants, it is now possible to measure directly an individual's total exposure at work and at home. Such measurements, applied in conjunction with models which account for time spent at home, in recreation, commuting, etc., will improve EPA's knowledge of actual 24-hour exposure, the spatial representativeness and temporal variability of ambient concentrations and, consequently, estimates of actual health risks.

Research is needed, however, to develop methods for more realistically determining exposure to other pollutants. For example, little information is available about hazardous air pollutants, their concentrations and distribution. Research is now attempting to resolve the arguments about estimating cancer risks, evaluating mutagenic hazards, determining effects to reproductive systems and estimating the potency of toxic pollutants. Since people cannot intentionally be exposed to hazardous pollutants, this work is further confounded by the uncertainties associated with extrapolating from data on animals to prediction of effects on humans.

Currently, hazard assessment documents are being prepared on potentially hazardous air pollutants. In addition, determining the potential interactions of these pollutants to form products of greater or lesser toxicity remains a major research challenge. However, one of the problems with field measurements is that, in many cases, measurement technology is inadequate to detect and measure such pollutants in ambient air. Technologies for making measurements in the ambient environment are now being modified or developed, especially for measuring organic compounds and particulates found in urban atmospheres.

Air pollution may pose greater risks to the health of certain more susceptible groups of people than to the remainder of the population. Research is looking increasingly at populations at presumed greater risk. Similarly, health studies of ambient air pollutants such as ozone and nitrogen oxides using test animals now concentrate on chronic, long-term, low-dose exposures. The lower doses often portray more accurately the pollutant levels seen in the environment. Such long-term, low-dose health research may help to determine if linear or non-linear dose-response curves more accurately estimate the probability of human health impairment from exposure to low doses of air pollutants.

Other air pollution research will improve the scientific basis of models, validate models in the field, and improve laboratory methods to refine the models. The models range from atmospheric transport, transformation, diffusion and deposition models, to biological tests that can be used to determine the presence of certain compounds and to screen compounds for potential toxicity. Once these models are developed, they will be tested for accuracy.

Major Research Topics

Of the 14 major topics which are part of our air-related environmental research program, five address health issues, three monitoring and quality assurance, four environmental processes and effects, and two engineering. These topics are grouped accordingly in the following discussions.

Extrapolation modeling: How can EPA's risk assessment capabilities for air pollutants be improved through the use of extrapolation modeling? Such modeling techniques allow for better extrapolation of health or exposure data from high dose to low dose and from animal data to humans.

One of the greatest sources of uncertainty behind EPA's public health regulatory function is the absence of solid, quantifiable data on human health effects. This gap is not easily filled by direct research — one cannot intentionally expose human subjects to potentially hazardous substances. Hence, EPA must sometimes make its regulatory or enforcement decisions regarding public health protection without any human exposure data.

Even where human health data exists, it is often based upon short-term, high-level exposures which may not be directly relevant to the types of low-level, long-term chronic exposures which are more typical of environmental conditions. Existing epidemiologic studies of substances are seldom sufficiently quantitative to support risk assessments, and new studies in response to toxic pollutant episodes encounter severe logistical difficulties.

In the face of this paucity of direct human exposure data, EPA is developing techniques to yield improved risk assessments. When fully developed, these techniques will allow extrapolation from animal to human effects, from high-dose to low-dose effects, or from short-term to long-term health effects.

EPA's research is developing and validating theoretical models of several major biological processes relevant to use in extrapolation models. These include: modeling respiratory tract deposition and uptake of oxidant gases, sulfur oxides, and particles (alone and in combinations); improving available regional deposition data in animals and using lung casts to examine this deposition; improving physical and chemical data such as protective layer thickness; and determining interspecies sensitivities to oxidants at predicted equivalent concentrations. EPA is also developing neurotoxic response indicators which will be used to compare interspecies effects of hazardous air pollutants.

Major planned research products include:

- Regional dosimetry and species sensitivity to ozone, 1984
- Respiratory tract deposition of particles, 1985
- Comparative mathematical dosimetry models for oxidant gases, 1987
- Comparative lung morphometry between species, 1987
- Development of neurotoxic response indicators, 1988

Lung disease: What is the contribution of air pollution to the development of chronic lung disease?

Existing data indicate that healthy persons exposed to low levels of air pollutants experience alterations in pulmonary functions. Observed changes in lung function include increased airway resistance and altered lung alveolar macrophage activity. These results raise the possibility that either repeated acute physiologic responses or chronic low-level physiologic responses to air pollution exposure could contribute significantly to the development of chronic obstructive lung disease. Such a contribution could be either direct, or indirect through increased susceptibility to pulmonary infection or injury.

To investigate this question, EPA is sponsoring research into both short-term exposures of humans to air pollutants and long-term exposures of animals to the same pollutants. Through such research, we hope to relate acute responses in humans to acute responses in animals, acute responses in animals to chronic responses in animals, and chronic responses in animals to observed pathological changes in humans with diagnosed pulmonary disease. Fuller understanding of these relationships will allow predictions to be made regarding the relationship of observed acute responses in humans to the development of chronic changes in humans. The key scientific information gaps are: What are the effects of these pollutants and at what levels of exposure? What are the mechanisms of effects observed? What are the roles of adaptive mechanisms? What populations are more sensitive to the development of chronic effects? How do these developments offer early indications of chronic effects?

This research topic is closely related to topics of improved extrapolation modeling and sensitive populations. Additional research being performed by EPA which will be used to address this topic is described at greater length under those two related issues. In summary, the human volunteer and animal exposure studies on oxidants, carbon monoxide, sulfur oxides, and airborne particles will provide data, and extrapolation modeling techniques will be used in defining or predicting the relationships described above.

Major planned research products include:

- Effects of oxidants on the susceptibility of young rats to infection, 1985
- Response of patients with chronic obstructive lung disease to ozone and sulfuric acid exposures, 1986
- Effects of chronic exposure to oxidants on normal rats and rats with lung disease, 1987
- Sub-chronic effects of sulfates and sulfur dioxide on lung morphology and physiology in rodents, 1987

Sensitive groups: What are the effects of acute exposures to air pollutants on sensitive population groups?

Some groups of people are more susceptible to harm from exposure to air pollutants than other groups. To assure that the people who are most sensitive to air pollution have an adequate level of health protection, as required by the

Clean Air Act, accurate data is needed to determine the precise nature of their health responses. Among the groups identified as most sensitive to air pollution harm are pregnant women and their fetuses, children, the elderly, asthmatics, those with chronic obstructive lung disease, and people with coronary artery disease.

EPA's air pollution research provides major contributions to the scientific knowledge data regarding air pollutant health effects. The existing data base for effects in healthy people demonstrates that some persons exposed to air pollutants exhibit responses such as increased sensitivity to bronchoconstrictors (substances which cause the lung's air passages to narrow down, thus restricting air flow) and increased airway resistance. Such responses have been seen either from constant or intermittent exposure to low levels of pollutants over a period of time, or from low levels of exposure with repeated higher peaks.

The oxidant pollutants, carbon monoxide, sulfur oxides, airborne particles, lead, and hazardous air pollutants each may affect different susceptible population groups. Key questions which science needs to address are: What are the effects of these pollutants, upon which population groups, and at what exposure levels? What other factors influence dose-response relationships? What are the mechanisms of action involved, and how do adaptive mechanisms come into play? What are the effects of exposure to combinations of pollutants?

EPA's research to address these questions includes both clinical and animal studies. The clinical studies use volunteer human subjects exposed to pollutants in EPA's clinical exposure facility. These persons are exposed, both at rest and while exercising, to pollutants at concentrations bracketing actual ambient levels. All exposures are acute (short-term) exposures. Subjects are tested before, during, and after exposure to determine pulmonary function performance, effects on biochemical parameters, and effects on peripheral lymphocytes (an index of immune function).

Normal, healthy individuals, in addition to other groups which may be more susceptible, are being exposed to low levels of ozone, NO_2, SO_2 and fine particle aerosols alone and in combination. These tests will characterize, to the extent possible, thresholds of effects. Asthmatics will be studied using ozone and nitrogen dioxide as well as sulfur dioxide, both alone and in combination with aerosols designed to model ambient conditions. Persons with preexisting conditions such as alpha-1-antitrypsin globulin deficiency, which may predispose them to increased pulmonary responses, such as increased airway constriction or changes in pulmonary capacities or in the function of pulmonary lymphocytes, will be studied using the same pollutants. In addition, non-invasive methods using a gamma camera to measure the heart's ventricular wall motion will be used to study effects of carbon monoxide on people with existing coronary artery disease such as angina. There is great interest in this study as it, together with the results of other research being conducted outside of EPA, is expected to significantly improve upon the earlier data used by EPA to set an ambient air quality standard for carbon monoxide.

EPA's animal studies will employ the same pollutants as those mentioned above for the human exposure studies; however, in animal studies the focus will be on effects of long-term (chronic) exposures. These animal studies are investigating both the increased susceptibility to respiratory infections and the development of arteriosclerosis to determine whether they are influenced by exposures to air pollutants. Additional studies will apply long-term (chronic) exposure regimens to both healthy rodents and those treated to simulate conditions such as asthma or emphysema. Differences in sensitivity among various species of small mammals will be investigated.

While no epidemiology studies are currently being performed by EPA in this area, we are sponsoring a feasibility study to determine whether epidemiologic studies can be performed at low levels of ambient pollutants which will produce results that are directly useful to EPA's regulatory functions. This feasibility study will be completed in 1985. The effects of air pollutants upon sensitive population groups is a key concern to be addressed by this study.

Recent research has indicated neurological effects from lead at lower levels than expected. Those effects of particular concern are reduced numbers of synapses in newborn animals whose mothers had high lead levels and slowed peripheral nerve conduction velocities in children exposed to lead. EPA is planning studies to follow up these indications and to further characterize lead exposure/absorption/retention relationships in sensitive groups.

Major planned research products include:

- Asthmatic responses to sulfur dioxide exposure, 1984
- Pulmonary effects of oxidants in asthmatics, 1985
- Neurobehavioral effects in children to exposure to lead, 1985
- Epidemiology feasibility study results, 1985
- Left ventricular function and angina in coronary artery disease patients exposed to carbon monoxide, 1987

Cancer: What is the contribution of air pollution to lung, and other types of cancer?

EPA is developing a long-range research program that addresses the major scientific uncertainties regarding the relationship between air pollution and human cancer. This research will investigate the methods and data base needed to identify the major sources of airborne carcinogenic chemicals. Such chemicals may either be emitted directly into or may arise from atmospheric transformation of precursor chemicals. Through such research, EPA seeks to develop the tools necessary to produce quantitative, comparative, or relative risk evaluations to estimate human cancer risk from both complex source emissions and individual chemicals. The major questions to be addressed, and EPA's planned research approach, are discussed below.

In 1977, and again in 1982, international meetings were held in Stockholm, Sweden, to address the relationship between air pollution and cancer risk. Data presented at these meetings indicates that air pollution from fossil fuel combustion, perhaps in combination with cigarette smoke, is responsible for ten percent of the incidence of lung cancers in large urban areas. Other researchers (Karch and Schneiderman, 1981) argue that past analyses of this problem have overestimated the contribution of smoking and underestimated the multicausal nature of cancer. They estimate that between 11% and 21% of lung cancer is related to air pollution.

This is an important issue for EPA. The answer to the question "To what extent is air pollution related to lung and other types of cancer?" could have a major impact on EPA's research and regulatory priorities.

EPA plans call for a series of workshops bringing together expertise in cancer epidemiology, carcinogenesis, mutagenesis, and risk assessment to address such major issues as: To what extent can we now quantify the relationship between air pollution and lung cancer, and how can such estimates be improved? Can we estimate the relative importance of gaseous organics versus particulate-bound organics? Should only lung cancer be considered in relation to air pollution? Is there now sufficient evidence that air pollutants can induce cancers in organs other than the lung (e.g., bladder cancer associated with coke oven and diesel truck emissions, or liver cancer from exposure to chlorinated hydrocarbons)? And, finally, can the method developed in the EPA diesel research program to estimate cancer risk based upon the comparative carcinogenic potencies of the materials tested be used to estimate human cancer risk from different combustion sources (e.g., wood stoves)?

Major scientific information gaps keep us from being able to adequately evaluate and quantify the contribution of various air pollution emissions to cancer risk. EPA is developing a research program which will address some of these gaps. As part of this research, EPA will use mutagenicity assays to evaluate gaseous and particulate emissions from various combustion sources. These samples will also be chemically fractionated and bioassayed in order to determine the relative contribution of each chemical class fraction to the total mutagenic activity of the emission sample.

Bioassay techniques have been developed to the point that they can be used to monitor both indoor and outdoor exposures. EPA researchers intend to couple bioassay monitoring techniques with personal and microenvironment chemical monitors to better define individual human exposure to mutagens and potential carcinogens.

Source apportionment and emission source data will be used together to estimate the relative contribution of each source. Emission sources to be evaluated include residential wood, coal, oil, and kerosene combustors, coke ovens and mobile sources including jet aircraft and gasoline engines.

EPA's research has developed computerized structure-activity methods which will be used to compare mutagenicity/carcinogenicity data bases with listings of compounds identified in mutagenic fractions. Such efforts should enable us to more rapidly identify potentially carcinogenic air pollutants. Emphasis will also be given to evaluating the sources of compounds found in ambient air and their relationship to emissions. Related EPA studies are examining the influence of ozone, NO_x, SO_x, and other atmospheric conditions on the formation and persistence of mutagens and carcinogens in the atmosphere.

Major planned research products include:

- Bioassay monitoring techniques, 1984
- Mutagenic and carcinogenic activity of source emissions, 1986
- Identification of potential mutagens and carcinogens from ambient air, 1986

Non-ionizing radiation: What are the health effects associated with environmental exposures to non-ionizing radiation (NIR) at frequencies from 60 Hz to 3 x 1011 Hz?

EPA will soon issue guidance which sets limits for public exposure to radiofrequency (RF) radiation. This guidance will be based, in large part, upon EPA's comprehensive review of the available literature on the biological effects of RF radiation. This document covers the frequency range of 0.5 MHz to 100 GHz. The reported consequences of the interaction between RF radiation and biological systems are critically evaluated and include examination induced core temperature increases, whole-body-averaged specific absorption rates associated with biological effects, the exogenous energy burden as a percentage of resting metabolic rate, and epidemiological studies.

One product of EPA's literature review has been the identification of the major scientific uncertainties and unknowns in our current state of knowledge. EPA's health research program is addressing some of these data gaps for the purpose of determining whether exposure guidance should be modified in the future or extended to cover frequencies beyond those covered in the current review document, for example below 0.5 MHz and beyond 100 GHz.

Our research strategy is to investigate the interaction of NIR with biological systems in animal models and cellular test systems. Our focus is on site-specific effects from low-level chronic exposure — interactions which are presumably not related to increases in temperature. We are developing combined electromagnetic-heat transfer models to predict the thermal responses of animals and man to the absorption of electromagnetic energy. In addition, we are investigating the biophysical and biochemical changes that occur as a result of exposure to NIR, including extra-low frequencies (ELF) such as 60 Hz. Research on 60 Hz radiation will be closely coordinated with the Department of Energy. EPA is also studying the immunologic, neurotoxic, metabolic, and reproductive and fetotoxic effects of NIR and the long-term human health effects of RF exposure.

Major planned research products include:

- Review document on RF health effects, 1984
- Interactions of NIR with central nervous system tissues, 1984
- Mortality and morbidity in a radar-exposed population, 1985
- Biophysical and biochemical effects from exposure to ELF radiation, 1987
- RF effects on lifespan of rats, 1988
- Development of thermophysiologic predictive models, 1989
- NIR interactions with membrane and biopolymer test systems, 1989
- NIR effects on immunologic, reproductive, metabolic, and neurologic systems, 1989
- NIR interactive frequencies with biological systems, 1989

Indoor air: To what extent do indoor sources of and exposure to air pollutants contribute to health risk?

Since people spend 80-90% of their time indoors, a major part of their exposure occurs there. In response, EPA is increasing its research to identify the major sources of indoor air pollution to determine human exposure to these pollutants, and to assess associated health risk. Recent EPA research efforts include monitoring studies of four large buildings (a school, a home for the elderly, an office building, and a hospital) for levels of volatile organics, formaldehyde, pesticides, and respirable particulates. In addition, a field study is being completed to develop simple, inexpensive and well-characterized indoor measurement methods for radon.

In 1984, our research will expand to include larger field studies, increased efforts on determining source emission rates such as emissions from building materials, combustion devices, and maintenance materials, and studies to characterize the factors influencing emission rates and human exposure. A methods development and evaluation program will also be continued, concentrating initially on evaluating instruments for measuring inhalable particulates and developing a practical instrument for measuring indoor NO_2 concentrations. Close coordination with the other Federal agencies conducting research in this area — including the Department of Energy, Consumer Product Safety Commission, and the Department of Health and Human Services — will be a feature of this research effort.

Major planned research products include:

- Source emissions studies, 1985

- Design for pilot national field monitoring, exposure, and health effects study, 1985
- Validate and/or improve measurement devices for key indoor air pollutants, 1985

Human exposure: What monitoring capabilities will allow accurate determination of actual human exposure to air pollutants?

Effective modeling, control, and regulation of air pollution depend on rapid and precise methods to measure air pollutant concentrations not only in the ambient atmosphere and from specific pollutant sources but also in the human breathing zone. This means that an underlying theme of EPA's monitoring research is the development of new measurement methods and of quality assurance programs to ensure that methods currently in use are reliable for all three areas—ambient, source and personal monitoring.

In addition to working to improve site monitors, EPA research will develop non-invasive monitors to gather physiologic data while collecting exposure data. These monitors will be miniaturized for use in field studies to gather accurate data under actual ambient conditions.

Similar to the proposed change in the particle standard, there may be a change in the way of calculating personal exposures to hazardous air pollutants. Currently, exposures are estimated using data on the emissions and measured or calculated concentrations of pollutants in the ambient atmosphere. However, total exposures based on actual 24-hour personal exposures may differ from those estimated from the ambient concentrations. For example, recent tests indicate that actual total personal exposures to a number of airborne carcinogens and mutagens may be two to four times greater than outdoor measurements would indicate.

For measuring personal exposures, EPA is developing new methods to work in concert with the new or modified technology for measuring ambient exposures. The results, which may be definitive within the next half decade, will help to determine the appropriateness of the current regulations for the EPA's seven listed and four regulated hazardous air pollutants as well as the potential need for regulations for other pollutants. The research program for developing and employing instrumentation to measure hazardous air pollutants is expected to gain increasing emphasis during the next few years.

EPA, together with the Motor Vehicle Manufacturers Association, is funding a Health Effects Institute (HEI). The HEI is an independent, non-profit organization developed to design and conduct research concerning the health effects of emissions from mobile sources. Complementary EPA research on mobile sources seeks to determine the extent of human exposures to mobile-source pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), diesel particles and unregulated organic emissions. Continuous, real-time personal monitors are presently being used to measure CO concentrations. NO_2 badges sensitive enough to provide data on exposures at ambient concentrations have been developed. Portable devices capable of collecting airborne particles for laboratory analysis have also been developed. Measurement and analytical procedures for unregulated pollutants, however, need to be refined or developed.

Refinement and application of analytical procedures that apply to a variety of unregulated mobile source pollutants such as methanol and formaldehyde is needed. Research work is attempting to develop bioassay tests and analytical procedures applicable to emissions from various fuels and fuel additives. Initial work has been completed evaluating some diesel fuels derived from coal and oil shale, and work continues on the bioavailability of particle-bound organics.

A part of the mobile sources research program will be an analysis of the results obtained from a major study of human exposures to CO in Washington, D.C., and Denver, Colorado. As the first statistically representative data base on human exposures for a criteria air pollutant, it will serve as the research benchmark for data bases to be developed for the other mobile-source air pollutants. Even though nationwide CO emissions have been decreasing, the relationship between vehicle emission rates and actual CO exposures needs to be more precisely determined. By developing a reliable predictive method for determining population exposure profiles in urban areas, CO exposures can be determined and exposures to other mobile source-generated pollutants can be inferred using the CO data as a surrogate. The most critical portion of this work is development of a model to predict exposure to mobile source emissions as a function of vehicle emission rates.

The research approach in the Washington/Denver study was to develop a data base of information collected by volunteers who carried miniature carbon monoxide monitors developed by EPA. These monitors were used to measure both ambient CO and alveolar CO from the volunteer's breath samples. Alveolar CO is an indicator of the total body burden of carboxy-hemoglobin in the blood. By choosing a cross-section of the population, correlations made between exposures and urban-scale activities can be used as scientific estimates of realistic exposures to pollutants from mobile sources.

The results from the Washington/Denver study are also expected to indicate whether existing, fixed monitoring sites for measuring air pollutant ambient concentrations are sufficiently representative of actual CO exposure concentrations.

The exposure data can be used to: assess better the health risk of CO to the population, provide a basis for improving the siting of existing monitoring stations, and validate existing exposure models. Validation is particularly important. Field data are needed to further validate estimates used in establishing the National Ambient Air Quality Standard for CO. Those estimates were statistical approximations of the percent of the population exposed to various

CO concentrations. Actual exposure data are essential for determining whether future emission standards or air quality standards should be relaxed or made more stringent. Exposure models field-validated for CO will be important for other mobile source pollutants as well.

Data from the personal monitors will also be used to validate and improve existing computerized human exposure models such as the SHAPE (Simulation of Human Air Pollution Exposure) model. Such models are used to assess the impacts, in terms of exposure, of changes in emissions and activities. The product of this research will be an operational model which can be used to predict exposure to a substance directly from vehicle emissions data.

To assess the proper level of control of particles from diesels, information is needed on projected exposures of populations to diesel particles and the long-term health effects from the exposures. Health effects studies are being completed. Estimates of the carcinogenic potency of various substances, such as diesel particulates and unleaded gasoline, will be updated as needed based upon EPA and other research. There is a continuing effort to determine emission rates for many of these pollutants. Such source studies of emissions may provide important input into determining the type and cost effectiveness of alternative emissions reduction strategies.

For gasoline-fueled cars and light-duty trucks, emissions controls are relatively mature. For these sources, research focuses on developing more precise emissions inventories for volatile organic compounds under different driving conditions. Such information is important for maintaining air quality standards. For other vehicles — especially heavy-duty trucks and buses — research will aim at determining the impacts on air quality and human health of alternative emissions reduction scenarios.

The oxidants program will develop measuring methods to help determine the reactivity of air pollutants and the photochemical formation of smog. Emphasis of the program will be on refining existing monitoring technology and quality assurance.

Hazardous pollutants: What technologies and data are necessary to identify and quantify hazardous air pollutants?

For hazardous air pollutants, monitoring technologies and measurement methods are needed to determine precisely trace pollutant concentrations and to help to identify those air pollution components that represent a significant health risk. Protocols for the new air quality measurement technology must be developed, field-tested, and verified. Most existing methods of monitoring organic vapors employ polymer collection capsules in conjunction with a gas chromatograph (GC) and mass spectrometer (MS). However, some compounds known to be biologically active cannot be collected with the current polymer capsules. An EPA sponsored technology to supplement the GC/MS measurement process and the tunable atomic-line molecular spectrum (TALMS) device uses magnetic field excitation to identify compounds. EPA research is currently developing a library of spectra for use in identifying compounds.

EPA's research approach is to take measurements with state-of-the-art equipment while simultaneously developing, testing, refining and verifying new technology. EPA is establishing a regional monitoring center that can perform the sophisticated analyses necessary to detect hazardous air pollutants. The center will also act as a testing and evaluation laboratory for new stationary or mobile source measurement technology.

As the new monitoring and measuring technologies are developed, they will be used for identifying, screening and characterizing hazardous atmospheric pollutants. Emphasis of this research will be on quantifying the atmospheric transport and transformation processes (i.e., chemical reactions and dispersion) that govern the ambient concentration distributions of primary and secondary (derivative) hazardous air pollutants. Emphasis will also be on determining the effects environmental processes have on the frequency of occurrence, ambient concentration ranges, and patterns of variability observed for hazardous air pollutants.

We classify the hundreds of potentially hazardous atmospheric contaminants into the following broad categories: volatile organic chemicals, semivolatile organics, organics associated with particulates, and trace metals. Each group requires different sampling and analysis techniques, and for each group, we apply a specific research strategy.

Volatile organic chemical substances include human carcinogens (benzene, vinyl chloride), suspected human carcinogens (chloroform, carbon tetrachloride), co-carcinogens or promoters (n-decane, n-dodecane), and bacterial mutagens (styrene, dichlorobenzenes). Until recently, volatile organic chemicals could not be sampled at normal atmospheric levels (approximately 1 ppb). With the introduction of Tenax-GC, a synthetic polymer with great affinity for these compounds, it has become possible to sample and measure them at typical atmospheric levels. Since these compounds make up a large portion of the potentially toxic air pollutants being evaluated by EPA's Office of Air, Noise and Radiation, it is important to obtain detailed information on their environmental concentrations. We intend to establish three trend monitoring sites in urban areas in 1984, to be expanded to 15 sites in 1985. We also plan, for one urban area, to conduct a concurrent effort to obtain detailed information on the spatial and temporal variation of both ambient levels and human exposures.

Some volatile organics, such as vinyl chloride, methylene chloride, and formaldehyde, cannot be measured by Tenax-GC methods, and must be sampled and analyzed by other methods, such as direct cryogenic trapping or use of a molecular sieve (for formaldehyde). Our research will seek to improve both the accuracy and cost-effectiveness of such alternative methods.

Semivolatile organics, especially chlorinated pesticides such as DDT, aldrin, dieldrin, lindane, and chlordane, together with PCB's, can be sampled using polyurethane foam (PUF) as a collecting agent. These compounds are still found in air, even though controlled or banned by EPA. They continue to be emitted from soil treated with termiticides and from hazardous waste sites. The PUF technology has made it possible to determine low ambient levels of these biocides.

Organics associated with particulates, such as dioxin-contaminated soils, are often very difficult to measure. A major effort has been made to develop ways of measuring such agents in water, ambient air, stack emissions, and soil. New sensitive methods have been developed and evaluated, with field tests scheduled for the near future.

Other particulate-bound organics are associated with combustion processes, particularly of coal and wood. Benzo-a-pyrene and other polyaromatic hydrocarbons (PAH's) cannot now be measured without sampling huge volumes of air. New methods such as synchronous fluorescence and room-temperature phosphorescence give promise of providing accurate measurements using small samples of air. Such methods would allow indoor and personal sampling. These methods will be further developed and tested in our field studies.

Trace metals are easier to measure than the other three groups of substances. A nationwide monitoring network has collected data on ambient levels for 15 years. However, exposures in homes or automobiles are important for some elements (lead, arsenic) and, therefore, smaller samplers capable of collecting particles inside homes, automobiles, and other microenvironments are desirable. A small lunch-box size monitor developed by the National Bureau of Standards for EPA will be tested to determine its suitability for measuring exposure to trace metals over a 24-hour period.

The priorities of EPA's research into hazardous air pollutants will be guided by two forces — the EPA's (Office of Air Quality Planning and Standards) program of screening potential airborne toxics and the need to detect actual mutagens and carcinogens measured in the urban air. It is a relatively recent finding that genotoxins in urban air are ubiquitous and apparently related to a variety of combustion/fuel type sources.

After screening approximately 600 high production volume chemicals, EPA's Office of Air Quality Planning and Standards has identified approximately 40 compounds as being of high priority for further investigation. Research during the next two years will assess the health risks and determine the sources of these chemicals, assess other potential hazardous chemicals, and evaluate technologies for reducing or eliminating HAP emissions. A variety of conventional residential heaters will be investigated to determine the types and magnitude of hazardous pollutants emitted directly or formed via secondary reactions in the atmosphere.

Technology assessment work will focus on potential HAPs which are being evaluated by OAQPS for possible regulation under Section 112 of the Clean Air Act. Examples of potential HAPs which may require technology evaluations for controlling their releases include ethylene oxide, chloroform, chlorobenzene, cresols, phenols, 1,3-butadiene, and nitrosamines (and their precursors). The potential HAP compounds will be classified into various groups (e.g., gaseous, particulate, fugitive, point source, condensible, water soluble, etc.) for the purpose of determining their controllability by various generic air pollution control systems. This initial evaluation will enable conclusions regarding the effectiveness of existing control technologies in controlling HAPs.

Measurement activities will concentrate on developing sampling and analytical procedures required to perform source assessments and to evaluate control technology efficiencies for the chemicals selected by OAQPS, and on modifications to previously developed screening procedures for identifying additional compounds which may also contribute to hazardous pollutant emissions.

This research will also provide data on the influence of NO_x on the formation of hazardous compounds (e.g., nitrated PAH), the role of secondary reactions, and the health effects of pollutions emitted.

Major planned research products include:

- Establish three trend monitoring sites, 1984
- Complete 15-station trend monitoring network, 1985
- Complete wood and coal stove emission exposure testing, 1985
- Initial assessment of selected HAP source, 1985
- Technology assessment for selected HAPs and industrial categories, 1988

Models: What models best describe the regional, mesoscale, and urban scale transport and transformation of pollutants?

When pollutants are emitted into the atmosphere, they often undergo chemical and photochemical reactions that change the initial pollutants into a range of different compounds. To predict this phenomenon requires that chemical process equations (e.g., for reaction rates) and physical process algorithms (e.g., for dispersion) be integrated into one model. Regional, mesoscale and urban scale transport and transformation models are being developed for sulfur dioxide, sulfates, particles, ozone, nitrogen dioxide and nitrates including natural emissions of hydrocarbons. The models will provide information necessary to develop effective pollution control plans for a variety of air pollutants.

Lagrangian models are being developed which describe the motion of air parcels by specifying a conceptual "parcel or volume of air" and tracing its motion over time. These methods generally assume that the rate of change in the concentration of a given pollutant is constant. Such methods do not work well when the reaction rate for the pollutant of interest is affected by other factors (e.g., other pollutants). Such models are less costly to operate and require less data than fixed coordinate (Eulerian) models. Depending upon the specific application, one or the other type of model may be more appropriate and more useful.

Eulerian (fixed coordinate) models are useful in support of air quality managers. Such models describe the motion of air parcels on a grid of points in space at a particular time. The Eulerian methods can require extensive computer time and can include the non-linear chemical calculations needed to predict the downstream reactions that form ozone, sulfates and nitrates. The methods also are applicable to long-range, or regional, transport. EPA's research program is applying this approach in developing the agency's regional photochemical transport model.

The regional scale model development and verification program will depend upon data collected during the Northeast Regional Oxidant Study (NEROS)/Persistent Elevated Pollution Episodes (PEPE) program. The regional scale model will be tested and refined using this field data. A few European countries have expressed interest in using the models and adapting them with their data base.

The regional photochemical model will be a reactive model. That is, it will be capable of handling a number of complex chemical reaction mechanisms for ozone and particulate matter. The model's 1984 version will address only ozone chemistry. A chemical mechanism for ozone, including both anthropogenic and biogenic organics, will be ready for use in regional models in 1984. Following that, the model will be developed further to include particle chemistry such as the reactions of SO_2 to sulfate, including aqueus-phase reactions. At a later date, nitrate chemistry will be added to the model. A field-evaluated model is scheduled to be available in 1986. After the model is evaluated, studies will be conducted to define the level of uncertainty in the model's predictions.

Urban-scale air quality models will also be developed for oxidants and particulate matter. One urban photochemical model is based on the empirical kinetic modeling approach (EKMA), much of which is derived from smog-chamber studies. By specifying the ratio of hydrocarbons to NO_x in the urban atmosphere, the EKMA will estimate the level of air pollution controls needed to achieve the ozone air quality standards.

Other types of air quality models for urban scale photochemicals and particles are mechanistic or physical models that simulate atmospheric transformation and dispersion processes. These models use more advanced chemistry and meteorology than does the mechanistic EKMA model. Most of the research to date has focused on developing and validating first-generation air quality simulation models. The models were tested against a comprehensive air quality and emissions data base obtained through a five-year regional air pollution study conducted in the St. Louis area during the mid 1970's.

Recent studies have shown that predicted pollutant concentrations derived from the use of different chemistry submodels show large discrepancies when the models are run with low HC/NO_x ratios. Such discrepancies could introduce errors when used in air quality simulation models. To resolve this problem, EPA will conduct indoor and outdoor used to develop improved chemical submodels of photochemical smog formation. Indoor smog chambers will be used to investigate the photochemical reactions of aromatic hydrocarbons and their oxidant products. Outdoor chamber studies of exposure to mobile-source pollutants such as carbon monoxide (CO), will investigate the effects of hydrocarbon composition changes on the formation of O_3 and other oxidants. Multi-day irradiations of complex VOC/NO_x mixtures will assess the oxidant-forming potential of "spent" air masses and provide the necessary data for use in a regional oxidant model.

This research will produce chemical kinetic data for use in either EKMA or air quality simulation models and a validated O_3 and NO_2 chemical module in EKMA. An updated EKMA model using improved O_3 chemistry will be available in 1984. Another significant research output will provide the EPA regulatory office with regional photochemical modeling results based on target emission reduction strategies provided by the Office of Air Quality Planning and Standards. These results will be available in 1986.

Research will also be conducted to develop and verify urban-scale models which predict one-hour, 24-hour, and yearly average values for urban particulates and can be expanded to include the contribution to these values of plumes from large sources at mesoscale distances (50-300 km). Improved urban and mesoscale particulate models will be produced for state and local governments and industry for use in SIP revision based upon the proposed new particulate standards.

Major planned research products include:

- Evaluation of a chemical kinetics mechanism for EKMA, 1984
- Report on urban particulate model evaluation based on Philadelphia air quality data base, 1985
- User's guide for linear Lagrangian regional particulate model, 1985
- Near-source fugitive dust field study results and comparison with models, 1985
- User guide on improved urban and mesoscale models delivered to user's network for applied modeling of air pollutants, 1985
- Regional ozone modeling results based on target emission reduction strategies, 1986
- Improved ozone chemical mechanism for use in urban and regional scale modeling, 1986

- **Final recommendation on boundary photochemical reactivity/volatility levels to assess the impact of VOC emissions on ozone air quality, 1987**

Complex terrain: How can air quality models reflect complex terrain conditions?

The Clean Air Act Amendments of 1977 require EPA to specify the use of dispersion models pertinent to prevention of significant deterioration and to attainment of National Ambient Air Quality Standards (NAAQS). However, no model has yet been developed which adequately describes dispersion in complex terrains.

EPA research will develop such modeling capabilities. Initial model development will use field measurement data and results from the EPA Fluid Modeling Facility (FMF) to evaluate the strengths and weaknesses of models currently used in the regulatory process. Concurrently, atmospheric dispersion models will be developed for stack-plume impaction (contact of the plume on an elevated terrain under stable atmospheric conditions). Field research will include tracer studies over moderately-sized terrain obstacles and a full-scale plume study at an existing power plant in complex terrain. These studies will provide data for evaluating the performance of dispersion models under conditions that cannot be adequately simulated in the FMF.

Subsequent research will evaluate the feasibility of transferring the models to settings of increased topographical complexity, applying the models during neutral or unstable conditions, and projecting the calculated one-hour concentration to three-and/or 24-hour average concentrations. Coordination and data exchange will be maintained with similar studies being performed by the Department of Energy and the Electric Power Research Institute. The initial goal of this effort is to produce an evaluated complex terrain model for stable plume impingement, including a user's guide. A longer term goal is the development of a more comprehensive model which will handle a variety of situations in addition to plume impaction.

Major planned research products include:

- Demonstration study of good engineering practices to establish effective stack heights with respect to emissions sources located in complex terrain, 1984
- Analysis of small hill impaction study, 1985
- User's guide for evaluated complex terrain model for stable plume impaction, 1986
- Extension of complex terrain dispersion model to increase topographical and meteorological sophistication, 1987

Pollutant fingerprints: Can sources of pollution be identified by the unique properties ("fingerprints") of their pollutants?

Air pollution samplers in current use can detect, identify and measure the amounts of several different airborne compounds. Current sample analysis techniques, however, do not provide information on the sources of the pollutants. Now, technology and procedures are being developed to identify the sources of pollutants through the identification of unique chemical signatures of the collected compounds. The concept is called source apportionment.

Source apportionment works by analyzing collected particles with X-ray diffraction, ion chromatography, neutron activation, scanning electron microscopy and other advanced chemical analysis techniques. If the particles in question have the same unique features characteristic of particles identified from certain sources, then the sources of the particles in question can be ascertained. At present, the applicability of source apportionment methods is limited by a lack of the type of emissions data necessary to determine industrial source signatures. Both collecting the requisite emissions data and verifying the chemical analyses and signature matching methods are important parts of this EPA research effort. Also important is the need for a consistent collection procedure and a data base on particulates from specific sources.

Source apportionment cannot, by itself, be used to predict air pollution concentrations. By integrating the apportionment data with urban particulate dispersion models, however, a hybrid model may be able to identify sources or, as the case may be, to predict pollutant types and concentrations at given urban areas under differing conditions. EPA will use data collected in Philadelphia to develop such a hybrid model. The immediate goal of the research is to develop and test a comprehensive receptor model for apportioning particulate mass to components from emissions sources.

Major planned research products include:

- Receptor model application to Denver aerosol, 1985
- Receptor modeling results for comparison with dispersion modeling results for Philadelphia, 1985
- Complete receptor model analysis of aerosol in four cities, 1986
- Improvement of particle resolving ability by means of attenuation corrections, 1986
- Validation of receptor model procedure based on optical microscopy and X-ray diffractions, 1987

Crop and forest damage: What are the costs of damage to crops and forests from air pollution?

Agricultural crops and forests can be adversely affected by air pollution. EPA has initiated a research program to measure the impact of air pollution on agricultural crops. The research, conducted in cooperation with several state and local governments, and federal agencies, will assess the impacts of ozone pollution on crop productivity. Data for the research will come from EPA's National Crop Loss Assessment Network (NCLAN).

Since ozone is believed to cause the greatest damage to vegetation, in 1984 and 1985 the program will continue to evaluate the impacts of ozone pollution through research conducted at sites located throughout the country. Crops typical of a region are grown using standard agricultural practices. They are exposed to ozone concentrations that span the range of air quality conditions. Open-top chambers are used in this research, because they are the most thoroughly tested field exposure systems and permit the best control of pollutant concentrations under field conditions.

Results from field investigations will be used to develop dose-response functions relating crop yields to different concentrations of ozone. Various mathematical relationships are being formulated, including one which assumes a threshold concentration. Dose-response information will be integrated with crop yield data and ozone air quality estimates gathered from counties across the United States. In 1984, this information will be used to provide a preliminary national assessment of the economic impacts of ozone on the productivity of major crops. Field research will include typical hay and forage crops which, when added to prior research account for the majority of U.S. agricultural production.

Research is also planned to quantify the role of soil moisture as an influencing factor in the response of crops to ozone and to evaluate the effects of high level espisodes and of low-level chronic conditions. Results of this research and data from the evaluation of ozone impacts on hay and forage crops are scheduled to be used in an updated (1986) national assessment of ozone impacts on agriculture.

Related research has shown that interactions with sulfur and nitrogen oxides influence the response of crops and trees to ozone. Both additive and synergistic effects have been observed, varying with pollutant type, concentration, and plant species. Research will evaluate the occurrence of such pollutant combinations to guide exposure regimes for dose-response studies.

Over the longer term, research may be initiated to determine the nature and extent of the impacts of gaseous air pollutants on forest ecosystems. This program would correlate the growth of major forest species with air quality to provide an indication of the magnitude of the problem. Field and laboratory studies would identify the cause and effect relationships between air pollution dose and forest productivity. The output from these studies would form the basis for analyzing the economic and ecological impacts of air pollution on forests, and for determining the effects of changing air quality on the nation's forests.

Major planned research products include:

- Preliminary national economic assessment of the impacts of ozone on crops grown on 75% of the U.S. crop acreage, 1984

- Evaluation of the occurrence of pollutant combinations in ambient air and the development of exposure regimes for dose-response studies, 1985
- Determination of the response of selected crops to changing air quality conditions which include constant low level and episodic ozone concentrations, 1985
- Characterization of the effects of ambient soil moisture changes on estimates of crop loss due to ozone, 1985
- Update to national crop loss assessment for ozone considering soil moisture availability, crop cultivar responses, and the hay and forage crops, 1986
- Initial results from the field correlation of the growth of major tree species with ozone air quality, 1988
- Dose-response studies of the growth responses of several tree species, 1989
- Initial integration of forestry data from growth correlations and dose-response studies with ozone air quality estimates to provide a preliminary assessment of impacts, 1991

VOC, NO_x control: What are the most effective emissions reduction technologies for volatile organic compounds and nitrogen oxides?

The most important barrier to reducing emissions of volatile organic compounds (VOC's) and nitrogen oxides (NO_x) is the variety of industrial sources. To develop and apply practicable control technologies requires close cooperation between industry and EPA.

Control technologies either remove air pollutants or reduce their formation by modifying production processes. At present, engineering knowledge is available to provide the necessary control technologies, but associated capital costs for air pollution control are major burdens to many industries.

For the oxidants, research will be initiated to determine the least-cost control alternatives for volatile organic compounds (VOCs) and nitrogen oxides (NO and NO_2), which are the major precursors of oxidants such as ozone. Priorities for this research are shifting. Large-scale demonstrations of emissions reduction technologies are being phased out in favor of less costly fundamental studies, pilot and prototype testing and evaluation, and technology transfer.

In widespread areas of the country, VOCs are a major cause of the non-attainment of the NAAQS for ozone. In response, EPA research is providing scientifically valid data bases, methodologies, models and control technology data on VOC's to regulatory decision-makers, government enforcement officials, and the regulated community. Control technology such as capture systems, carbon adsorption, catalytic oxidation, and thermal oxidation will be assessed to establish performance standards for new and existing sources of VOCs. New source performance standards now in existence will be reviewed and updated by EPA based on the best engineering information available. The main emphasis of this research program will be on providing EPA, state and local agencies with data on cost-effective and energy-efficient control alternatives for developing emission standards.

With regard to nitrogen oxides, research will be conducted to improve combustion modification (CM) methods for reducing NO_x emissions while improving industrial furnace performance. Prior work on utility boilers has proven that CM methods can be used to control NO_x. Future research efforts will tailor CM methods to the special characteristics of different furnaces (e.g., stoker boilers, oil field steam boilers, package boilers, cyclone, wall-fired burners and heavy oil burners).

Research will also develop a technical basis for estimating the lowest achievable nitrogen oxides emissions from current and future combustion equipment and fuels. This research will support technology development and enforcement activities. Emission reduction methods from stationary internal combustion (IC) engines using fuel modification and oil or exhaust gas treatment will also be assessed.

Major planned research products include:

- Evaluation of the use of stoker gas recirculation for NO_x and particulate control in stoker boilers, 1984
- Results of initial hardware modification studies for NO_x control of diesel and natural gas engines, 1984
- Use of lances for staging combustion air on refinery process heaters, 1984
- Identification of emission characteristics of industrial relief/safety systems as a function of waste gas quantity and quality, 1984
- Initial evaluation of industrial applications of catalytic oxidation, 1984
- Evaluation of primary air vitiation for NO_x control for cement kilns, 1984
- For VOCs, evaluation of full-scale carbon adsorption and thermal oxidation systems for emissions reduction in the industrial surface (roller) coating industry, 1984
- Carbon adsorption pilot plant unit will be available for fundamental studies to aid in the development of control standards for sources of VOC emissions, 1984
- Evaluation of feasibility and reliability of various methods for determing capture efficiency, 1985
- Evaluation of use of in-furnace NO_x reduction for fired heaters, 1985
- Performance optimization and evaluation of industrial boiler low NO_x heavy oil burners, 1985

- **Results of additional development work and field tests of capture efficiency methods, 1986**
- **Additional field tests of industrial catalytic oxidation applications for VOC control are planned, including evaluations of relationships between operating parameters, design specifications and performance (destruction efficiency). The result will be data on improved operation and maintenance procedures for reliable, cost-effective control technology use, 1986**
- **Evaluation of selective catalytic reduction for NO_x in both spark ignition (natural gas) and compression ignition (diesel) stationary engines, 1987**
- **Evaluation of use of in-furnace NO_x reduction for industrial boilers, 1988**
- **Test application of in-furnace NO_x reduction to utility boilers, 1989**

Coal combustion pollution control: What air pollution control technologies promise improved cost-effectiveness for controlling pollutants from coal combustion?

The use of abundant domestic coal for utility and industrial power generation is expected to continue to increase into the next century. The economic incentive to shift to coal is, however, tempered by the costs of controlling coal-related air pollutants.

Commercially available technologies can be used to control most of the air pollutants emitted from coal combustion processes. However, these technologies are expensive to install and to operate. As a result, one of EPA's priority research goals is to stimulate development of lower-cost pollution control technologies and to identify more cost-effective implementation strategies. The problem is not whether we can control pollutants from coal combustion; the problem is how can we reduce the costs of controlling these pollutants?

EPA's research approach involves both detailed engineering research and development and multi-pollutant systems optimization studies. The latter to provide EPA regulators with accurate engineering information on the cost and performance of new control technologies for use in such regulatory programs as improved compliance for existing sources, and bubble and emission trading policies.

EPA's engineering research and development is refining such flue gas desulfurization (FGD) technologies such as wet lime/limestone scrubbing, lime spray drying, and dry sorbent injection. The potential payoff is dramatic. For example, lime spray dryers promise sizeable reductions in both capital and operating costs relative to conventional wet scrubbing processes.

To control particles, EPA is investigating such advanced particulate control technologies as electrostatically enhanced fabric filtration, precharging for electrostatic precipitators, and simultaneous particle and SO_2 collection in particle control devices. Again, the potential for cost savings is great. For example, a recent discovery that large diameter electrodes can dramatically improve electrostatic precipitators (ESP) performance for high resistivity fly ash, has the potential to greatly reduce the cost of ESP's, especially for low-sulfur coal applications. Fabric filters and ESP's are currently the most effective technologies for controlling emissions of aerosols and inhalable particulates from combustion processes. Research will investigate the conditions under emissions of condensible materials which can cause high emission opacity.

With regard to nitrogen oxide control, EPA research on low-NO_x burners for pulverized coal is leading to a generation of low-NO_x burners that can be retrofitted to existing installations burning high sulfur fuels. In addition to reducing NO_x emissions, this technology yields significant SO_x control. EPA's fundamental combustion research has identified new combustion approaches such as an adiabatic precombustor that has the potential to reduce NO_x (through fuel-rich precombustion), SO_x in subsequent staged afterburning, and particulates by slagging capture of ash in the high temperature precombustor. If successfully developed, precombustor technology could be a candidate for retrofit to cyclone boilers and for conversion of gas- and oil-fired boilers to coal. Also reburning technology (the injection and combustion of secondary fuel downstream from the primary combustion zone) has been shown to reduce NO_x emissions substantially. This technology should be applicable to a wide range of coal-fired boilers and industrial processes. Both reburning and precombustor technology have the potential for SO_2 control through injection of sorbent materials under appropriate combustion conditions.

Simultaneous investigation of these advanced control concepts can result in innovative configurations of integrated control systems that minimize cost while maintaining or improving emissions and energy performance.

Engineering research which leads to reduce the capital investment and operating cost of pollution control technologies used on coal-fired boilers, and operations research to define integrated environmental control systems at the plant and multi-plant level are both areas of research that have high potential to offer very substantial reductions in the cost of converting coal to useable energy in an environmentally acceptable manner.

Major planned research products include:

- Pre-commercialization engineering results for a precharger ESP collector system for particulates from low-sulfur coal, 1984

- Cooperative industry-EPA evaluation of large diameter and other electrode configuration for low-cost particle control in ESPs, 1985

- Pre-commercialization engineering research results on electrostatic enhancement of fabric filtration, 1985

- Effects of physical coal cleaning on SO_x control options, such as limestone injection through multistage low-NO_x burners (LIMB), 1985
- Design and performance data on advanced spray-drying FGD systems, including mathematical design model, 1986
- Results from small-scale evaluations of new concepts of integrated SO_x/particulate control technology, 1986
- Engineering evaluation of lowest cost retrofit options for various levels of particulate control, 1986
- Analysis of lowest cost application of conventional technologies for control of SO_2, NO_x, and particles to reduce acid precipitation, 1986
- Evaluation of lowest cost application of integrated conventional and/ or advanced technologies for control of SO_2, NO_x, and particles to reduce acid precipitation, 1987
- Definition of the causes of near-stack opacity problems and an evaluation of feasible control options, 1987
- Research information on low-cost control options to support inhalable particulate (IP) standards, 1988

Long Term Trends

In several areas of air-pollution and radiation-related research our investments of the past decade are beginning to yield important advances in our knowledge of air pollution sources, effects and controls. In the health area, for example, over the next five to ten years our research will produce a great deal more data on the respiratory effects of acute and chronic exposures to criteria air pollutants. Within that time period, we plan to have completed an assessment of the contribution of air pollution to the development of lung cancer, and research to determine the health effects of exposures to non-ionizing radiation should be nearing completion. Emerging as higher research priorities will be development of methods to indicate the presence of harmful agents in biological systems, development of early indicators of harmful effects, and improvement in our ability to predict disease risks from harmful agents.

Also evolving over time will be increased research emphasis on improving methods to extrapolate from toxicological data to risk based on regional and interspecies dosimetry modeling, on developing biological markers to detect the presence of harmful chemical agents and to indicate their effects (especially neurological or immunological effects), and characterizing additive or synergistic effects from mixtures of chemical agents.

Perhaps the greatest potential for future research breakthroughs lies in the further detection and characterization of interactions between chemical agents and human genes which control the development of cancer (oncogenes). This and similar methods for linking mechanisms of action to prediction of risks will be a key part of future risk assessments.

Also relating to human health, we see increased emphasis upon efforts to monitor actual human exposures to potentially hazardous air pollutants. We will continue to emphasize total personal exposures to toxic pollutants where current studies indicate that indoor exposures can far exceed concurrent outdoor exposures. Important scientific discoveries that can be expected in the monitoring area over the next decade include methods to detect the compounds responsible for the major portion of the mutagenicity of complex ambient air mixtures. Such compounds may be the PAH's, nitro-PAH'S, N-nitroso or other compounds. In addition, methods and equipment can be expected which will allow us to collect the compounds of interest from the breathing zone of individuals and employ microanalysis methods to quantify exposures during normal daily activities.

With regards to environmental research the next five to ten years can be expected to reflect a decrease in emphasis on air pollution modeling on the urban scale. For example, most of the development work associated with urban ozone and particulate models will be completed. On the other hand, problems dealing with the long-range or regional transport of air pollutants, especially ozone and particles, will remain to challenge investigators over the next decade. Associated with long-range particle transport is regional scale visibility degradation problems.

Environmental processes and effects research, is expected to focus on field experiments to evaluate, verify, and improve regional scale air quality simulating models to predict pollutant long-range transport and transformation. We will need to extend source apportionment methodology to the regional scale. Also, with advances in computer efficiencies, air quality models with more complex chemistry and meteorology, will be developed and made available to the user community.

In addition to improved models, research can be expected to focus on such secondary effects as regional-scale visibility degradation, materials damage effects (e.g., soiling due to particulate matter) and the effects of air pollutants on forest ecosystems.

EPA's research into air pollution control technology will reflect the long-range trends of gaseous (SO_x) and particulate pollution levels and types. A gradual buildup of aerosols (inhalable, and fine particles) in the ambient air can be expected if current trends persist. Reduced visibility and increasing concentrations of inhalable particles may result. Point (stack) emissions will decline in importance compared to more difficult to control and defused sources of emissions. Transformation of SO_x emissions and particulates are expected to account for the majority of ambient aerosol buildup, especially in urban areas and in areas of high human activity.

New methods to prevent, reduce, or capture fugitive and condensible emissions will need to be investigated to support permitting activities. For example, we can expect the broad application of electrostatic particle charging techniques to induce particles to agglomerate and to be removed. In addition, high efficiency methods of SO_x removal from flue gases, or sulfur removal from fuels and wastes are expected to be a high research priority in the next decade.

Finally, as future air quality standards become more sophisticated, they are likely to become far more complex. For example, current standards are based upon simple mass concentrations and concentrations per-unit of output. To reflect advancing scientific knowledge and to more precisely control pollutants of concern, future standards may need to be differently based.

For instance, a fine particulate air quality standard may specify the particle size range to be regulated, as well as the mass concentration limit to be applied to that size range. Moreover, the relationships among the individual standards must be considered in order to achieve the optimum benefit. For example, visibility regulations in effect put constraints on a fine particulate ambient air quality standard, which may be targeted specifically for human health effects. A fine particulate standard, in turn, also has a bearing on acid deposition loadings, and so on.

To achieve such sophisticated and sensitive future standards, an array of new research tools will come into play. These include more powerful regional models which can attribute air quality or deposition standards back to specific states or emission regions. The contributions of far-away sources to the ambient levels in a given receptor area need to be known to permit an equitable allocation of the burden of controls in order to meet the specified ambient standard.

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Synthetic fuel pollution reduction: What control techniques are most promising for reducing pollution from synthetic fuels?

Combustion generated pollutants: How do boiler conditions influence key pollutant-related reactions?

Long Term Trends

6 Energy

Introduction

Within the last few years, adequate energy supplies and a decrease in the growth of overall energy demand have effectively reduced the short-term crisis orientation of America's energy policies. These developments are reflected in EPA's energy research program. The program has been reduced in scale, its efforts have been more clearly focused and the timeline for results has been extended. These changes have provided an opportunity to help resolve energy-related environmental problems at a more considered pace.

A number of major projects are planned or under way as part of the program's primary objective — to provide EPA offices, federal, state and local governments, and industry with the scientific information necessary for producing and using energy resources in an environmentally acceptable manner.

EPA's energy-related research addresses two major subjects: alternate fuels (including synthetic fuels from oil shale, tar sands, coal gasification direct and indirect liquefaction and limestone injection multistage burner (LIMB) emissions reduction technologies.

The alternate fuels program studies the pollutants generated in various processes, evaluates the transport, fate and effects of pollutants associated with the production and use of synthetic fuels, and investigates alternative emissions-reduction techniques. EPA-initiated research related to the synthetic fuels industry builds upon EPA's experience in analyzing waste streams, pollutant loadings, health and environmental effects, emissions reduction strategies, cost/benefit relationships and regulatory requirements of various energy technologies. Such research efforts will help the emerging synfuels industry by identifying potential health and environmental risks, and by providing information on the cost and effectiveness of pollution control strategies before plants are designed and built. To achieve these benefits, EPA has initiated an intensive program in cooperation with the U.S. Synthetic Fuels Corporation to characterize discharge and to assess emissions reduction technologies in pilot and commercial synthetic fuel plants when they begin operation. Such research will help to expedite the process of reviewing permits to build and operate synfuel facilities. The research will identify for industry technologies which can minimize pollutant emissions so that these can be incorporated at an early stage, rather than expensively retrofitted, if so required, after the plant is built.

EPA's LIMB and combustion research provides engineering and design information for promising emission reduction technologies for new and existing industrial and utility boilers. This information will be useful to states involved with the acidic deposition issue and for electric generating plants which may be required to further reduce their air pollution emissions.

The energy related research program for fiscal year 1984 has a budget of $15.1 million. This total is divided among the major research disciplines as follows: environmental engineering and technology, 83%, health effects, 15%, environmental processes and effects, 2%.

Legislative Mandate

Air and water pollutants and solid wastes from the production and use of fuels are subject to environmental regulations and enforcement specified in the Clean Air Act, Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, Toxic Substances Control Act, and the National Environmental Policy Act. EPA research to support regulatory policy and enforcement responsibilities is mandated, directly or indirectly, by these six federal acts.

In the synthetic fuels program, EPA is authorized to provide scientific information for the permitting process, for preparation of environmental impact statements, for consultation with the Synthetic Fuels Corporation in reviewing proposed new synthetic fuel facilities, for characterization of, and review of, alternative methodologies which reduce emissions and discharges, for evaluation of the need for pollution standards, and to assist federal, state, and local governments and industrial organizations. In addition, Section 131(e) and 143(b) of the Energy Security Act of 1980 directs EPA to provide scientific consultation on environmental monitoring technology and procedures to synthetic fuel projects supported by the U.S. Synthetic Fuels Corporation.

Background

LIMB Programs

EPA's research involving LIMB (Limestone Injection Multistage Burners) is producing fundamental, bench-scale, and prototype information in cooperation with boiler and burner manufacturers. In cooperation with the Federal Republic of Germany, the EPA program is seeking to develop information relating prototype engineering data with full-scale field applications.

Large coal-fired steam generators are major sources of NO_x and SO_x emissions. The EPA has developed and demonstrated advanced low-NO_x burner technology applicable to this class of sources. Many manufacturers are offering advanced burner technology for new and/or retrofit applications. There is also the proven wet flue-gas desulfurization (FGD) technology for more than 90% SO_x control; however, for retrofit, wet FGD may be difficult and costly to apply.

As an outgrowth of the low-NO_x burner development, the EPA is developing a potential alternative approach to achieve reductions of SO_x and NO_x of 50 to 60 percent for retrofit applications at significantly reduced costs (3 to 5 times less than wet FGD). This approach, which involves SO_2-sorbent injected through the low-NO_x burners or at other points in the boiler, is the LIMB technology mentioned earlier.

The technology has shown great promise in small-scale experiments. However, additional research and development is required to establish its applicability to existing boilers and to achieve its potential for higher SO_2 removals (70-90 percent) in new boilers. EPA's research toward these ends also includes investigation of different configurations of boilers and firing systems (e.g., wall- or tangentially fired). Bringing the technology to commercialization will entail demonstration on utility boilers of representative design.

Furnace injection of sorbents was attempted in the late 1960's and subsequently abandoned for two reasons. First, the SO_2 reductions were not competitive with those achievable with wet FGD, second, there were extensive technical problems with achieving sulfur capture and maintaining system operability. The LIMB system is being reconsidered for two reasons. First, control of acid-rain precursors may require a method which offers more modest control levels (50-60% of NO_x and SO_x) at a substantially lower cost than wet FGD, and, second, low-NO_x combustion systems may solve many of the current technical problems.

The research and development conducted to date has provided new insight on the ability to capture SO_x with a sorbent in a combustion environment. Fundamental and bench-scale experiments have shown that very active sorbents can be generated and high rates of sulfur capture can be achieved. They have also shown that thermal deactivation (called deadburning — a phenomenon whereby the sulfur capturing sorbent is made chemically inactive by exposure to the combustion process) alone does not prevent substantial sulfur capture. On the other hand, EPA's research has shown that interaction between the sorbent and mineral matter in the coal ash can lead to a substantial deactivation of the sorbent. Coal-type, sorbent type and sorbent injection location all mitigate this adverse effect on sorbent activity. In addition to the small-scale experiments, prototype tests have been run on full-scale burners in an experimental facility. The results show that SO_2 capture in the range of 50-60% can be achieved under realistic conditions. Overall the experimental work shows that substantial SO_2 capture is economically and technologically achievable through this approach. In 1984 emphasis will be placed on expanded R&D and preparation for full scale demonstration of the technology.

Synthetic Fuels Program

Research and development planning related to synthetic fuels has begun for the task of collecting data on a number of large synthetic fuel plants such as, Great Plains Coal Gasification Associates in North Dakota; Coal Water Coal Gasification in California; Parachute Creek (Union Oil Co.) in Colorado; and Geokinetics Seepridge Shale Oil Co. in Utah, which are expected to start up by the end of 1984. Very little environmental data is currently available on commercial-scale synfuels plants. In late 1983 several synthetic fuel plants became operational including Tennessee Eastman, Inc. Until then there were no full-scale synfuel facilities in the U.S., with the exception of small industrial low-BTU gasifiers and commercial-size retorts operated intermittently by Geokinetics and Occidental Oil Shale.

Most pollution reduction technologies have been applied only at bench- or pilot-scales. Some emissions reduction technology has been applied at full scale, but little data is available and major problems are known to exist. Given these limitations, initial research has evaluated foreign facilities, and has incorporated laboratory or pilot-scale research results into models to provide data on expected operations.

EPA has been collecting data from its own research activities and those of other federal organizations, private industry and foreign researchers.

To date, environmental data on synthetic fuel facilities has been derived from source testing of foreign commercial gasification plants in Yugoslavia (Lurgi type), Greece (Koppers-Totzek), and South Africa (Koppers-Totzek). Additional evaluations were performed on pilot plants of Texaco, Bigs, and Westinghouse systems. Control technique performance data were developed. Data has also been obtained from experiments such as performance tests of various solvents for removal of "acid gases" (primarily CO_2, H_2S, and other reduced sulfur compounds) run at the EPA-funded coal gasifier facility at North Carolina State University. Performance tests of pilot Stretford technology for control of H_2S in oil shale air emissions were conducted at Occidental Oil Shale's Logan Wash and Geokinetics' commercial-scale experiments.

A relatively new area of research is combustion testing. The Department of Defense, the Department of Energy, and the Electric Power Research Institute have tested various coal-and shale-derived liquid fuels for combustability and general performance in various mobile and stationary combustors. In 1982, EPA began to test emissions from combustion of synthetic and petroleum fuels in a full-scale industrial boiler and stationary diesel at EPA's Research Center in the Research Triangle Park.

EPA has worked closely with the Department of Energy (DOE) in many areas of synthetic fuels research and development. DOE provides detailed analysis of the product materials. EPA has developed and continues to improve upon screening methodology applicable as an indicator of appropriate emissions reduction technology. EPA has also co-sponsored with DOE the evaluation of a pilot Stretford

(H_2S removal) unit as well as emissions testing at the Department of Interior's installation at Fort Snelling, Minnesota.

In health and environmental research, EPA provides resources to DOE for cooperative research which addresses the carcinogenic and reproductive effects of synthetic fuel pollutants, the toxicity effects within aquatic and terrestrial systems, and the integration of fate and effects data to assess the health and environmental risks of synfuel industries. Output from research conducted by the National Institute for Occupational Safety and Health involving the occupational health effects of synthetic fuel pollutants is being used in risk analyses.

Through work with the Department of Interior, which administers the federal oil shale leasing program, EPA has gained access to the federal oil shale lease tracts in Colorado and Utah.

Major Research Topics

There are five major scientific topics addressed by the synthetic fuels and LIMB research programs. These topics are described in the following section. Please note that these decisions are meant to highlight our highest priority research areas and do not, therefore, include the full array of EPA's research in this area.

Pollutant and cost reducing technology: What configurations employing LIMB burners show promise of reducing emissions control costs?

In order to determine the commercial feasibility of LIMB further understanding of the observed phenomena is essential. The major areas where additional scientific information is needed are sorbent-ash interaction, coal properties, high-activity sorbents, particulate characteristics, and scale-up of the technology. Each of these information gaps is discussed below.

Sorbent-ash interaction: Prevention of sorbent deactivation by coal-ash constituents may be the key to the success of the technology. Whereas the interaction is a documented phenomenon, the mechanism of contacting and deactivation has not been established. An understanding of that mechanism may serve as the basis for solving the problem. Possible solutions include changes in sorbent composition, sorbent-injection location, and/or fuel-properties (e.g., coal preparation).

Coal properties: The level of sulfur capture achievable is dependent upon the individual properties of the coal being burned. However, sulfur capture is not directly related to either ash composition or sulfur content. If the technology is to be widely applicable, there must, therefore, be a method for predicting and/or measuring the impact of a specific coal's properties on sulfur capture and system operability. With regard to low-NO_x coal burners a complex correlation of NO_x emissions with fuel nitrogen has been derived. This correlation can be obtained using simple laboratory analysis methods. A similar approach is needed for the other coal impurities — mineral matter and sulfur.

High-activity sorbents: Laboratory studies have shown that sorbents can be generated which have significantly greater activity than those currently generated in combustion systems. If combustion system design changes can result in super-active materials being generated either externally or in situ, significantly improved sulfur capture may be possible.

Particulate characteristics: Sorbent mixed with coal ash can modify particulate characteristics in ways that affect boiler operability. In the boiler, the presence of calcium compounds (most sorbents are calcium based) can affect slagging and fouling characteristics, either adversely or favorably. This intrusion can, in turn, affect boiler heat transfer and steam-generation performance. Furthermore, the increased solids loading and changed fly-ash properties associated with sorbent injection can affect particulate removal efficiency. Further research to quantify and generalize the effects for different coals is needed to ensure that boiler performance is not adversely affected.

Technology scaleup: In scaling a technology up to commercial size, many problems may arise which cannot be foreseen at the smaller bench or pilot scales. In addition, the existing boiler population has a number of different types of firing systems and of boiler configurations. As a result, research is needed to develop reliable scale-up criteria. This research will provide the basis for prototype testing. To be broadly applicable, the research should address wall- and tangentially-fired systems, and should cover most typical existing boiler designs. In addition, criteria for application to new boilers are needed for situations where higher-SO_2 removals are required (e.g., 70% for low-sulfur coals). Demonstration on full-scale boilers will represent final proof of the concept.

The LIMB technology is being developed under EPA sponsorship and the agency has the major research and development (R&D) program in the area. The Electric Power Research Institute has funded some work on boiler operability questions and is considering an expanded R&D role. Several private organizations are also performing research. Demonstration of the technology will require close coordination with boiler manufacturers and utility companies. Outside of the U.S., related work is being performed in Germany and Austria. EPA's researchers maintain close communication with these efforts.

EPA's research strategy is straightforward: provide the information necessary to determine the potential of, and achieve commercial acceptance for, the LIMB technology. The key to meeting the scientific information needs discussed above is a thorough understanding of the phenomena that affect system performance. To this end, EPA's research strategy has six key elements; basic research, bench-scale research, pilot and prototype testing, process analysis and technology demonstration.

EPA's **basic research** aims at providing a fundamental understanding of the chemistry and physics of the phenomena which control this technology.

Our **bench-scale research** with experimental systems enables the agency to evaluate the design and operating variables under controlled conditions in a combustion environment.

Pilot-scale development provides a test system which resembles actual combustion system hardware. This is the first step toward applying the process to practical configurations.

Prototype testing provides the final experimental scale-up of the technology. Full-scale burners are tested in experimental equipment to optimize performance and establish scale-up criteria.

Process analysis establishes the system constraints and incorporates the R&D results into design guideline documents.

Finally, **demonstration** of the technology on a full-scale field-operating boiler is essential to establish credibility with industry. Based on the design guidance, specific hardware is designed and installed on one or more boilers. Long-term performance evaluations establish the emission reduction achievable and any effects on boiler-system operability.

EPA's R&D effort is concentrated on wall-fired boilers with emphasis on prototype testing. The wall-fired boiler demonstration, funded in fiscal year 1985, is planned to commence in 1986. Over the longer term, the R&D emphasis will shift to tangentially-fired systems.

Major planned research products include:

- Document sulfur capture of prototype commercial low NO_x burners, 1984
- Quantify the mechanisms for sorbent-ash interaction, 1985
- Effects of coal type will be correlated to fuel properties, 1986
- Generalized scale-up criteria for wall-fired systems, 1986
- Use of superactive sorbents and the impact of particulate characteristics, 1987
- Demonstration of wall-fired technology completed, 1987

Identifying Synthetic Fuel Pollutants: How can we most effectively identify the major air and water pollutants from synthetic fuel facilities?

Pollutants will be produced at various points in the synthetic fuel production and use cycle. The types of pollutants and their concentrations will vary, depending on the processes employed, plant design, and the ultimate use of the fuel. To develop adequate pollutant reduction technologies and monitoring plans, synfuel waste streams containing potentially hazardous pollutants need to be identified and their pollutant loadings determined.

EPA researchers will continue to study pilot-scale and full-scale synthetic fuel plants to identify and characterize plant emissions. Emissions of concern include leachates from oil shale solid wastes, wastewaters which are proposed for disposal with spent shales, carcinogenic polycyclic organic compounds, reduced sulfur species (some of which may be toxic), and hazardous fugitive volatile organic compounds (VOCs). Data collected in field characterization studies will be used as input for risk assessment studies.

This research, plus monitoring data collected on the initial domestic plant start-ups in 1983-84, will be used to assist permit writers in cases where similar feedstocks and/or conversion technologies are proposed. This will help to ensure the adequacy of environmental permits, impact statements, and monitoring plans produced for plants supported by the Synthetic Fuels Corporation. Research on synthetic fuels from coal, peat, oil shale, tar sands and heavy oil will target those fuel production processes which are most likely to reach commercial use at an early date.

In 1984, pollutants from an oil shale synthetic fuel facility will be studied at the Geokinetics Seepridge facility in Utah and other sites such as the Union B Parachute Creek site in Colorado. Research activities will include characterizing air emissions and the constituents of wastewater used to moisten spent shale piles, identifying and measuring leachate runoff, evaluating the physical stability of spent shale piles and evaluating the potential for local vegetation to take up toxic elements released by shale processing. For the next several years research emphasis will be on environmental monitoring and pollution control technology evaluations.

Large amounts of monitoring data are going to be generated by these plants. To ensure the viability and availability of these data, EPA has been working with the Synthetic Fuels Corporation (SFC) to develop environmental monitoring plans for SFC-sponsored projects including uniformity of data reporting and data management systems. This data will be the primary input to EPA's assessment of risks of synthetic fuel plants during the mid-1980's. Among the specific control technology evaluations which will be continued are: wastewater cooling tower emissions of hazardous organic materials from recycled process waters, toxicity of effluent from biological treatment systems, sulfur control and removal, and techniques for long-term disposal of solid wastes which may contain substantial amounts of complex organic residuals.

Major planned research products include:

- Characterization of leachate from raw mined oil shale, 1984
- Characterization of spent oil shale leachates, 1984

- Interpretive report on monitoring data for regulated and unregulated substances from operational synthetic fuel plants, 1985
- Results of comparative testing by EPA of combustion emissions from synthetic and petroleum fuels, 1985
- Emissions of organic vapors from cooling towers at plants that use process water for cooling, 1985
- Status of sulfur control systems for synfuels plants, including their performance and costs, 1985
- Report on performance of pollution controls at commercial synthetic fuel plants, 1986

Synthetic fuel pollutants risk: What are the health and environmental risks of synthetic fuel-related pollutants?

An accurate analysis of risks to health and the environment is needed in regulatory and enforcement decisions. EPA integrates exposure and effects assessments of synthetic fuel pollutant emissions into risk analyses which can be used to evaluate the potential health and environmental impacts of synfuel pollutants. The assessments consider meteorological, hydrological, demographic, and environmental characteristics specific to the location of synthetic fuel facilities.

EPA's research will produce technology-oriented risk analyses for coal gasification, direct and indirect coal liquefaction technologies, oil shale and other synthetic fuel technologies. These analyses can be used to examine the relative hazards of alternate sites, the cost/benefit considerations for locating the plant at different sites, the appropriate levels of pollution control, the hazards associated with not having additional control, and the reduction of hazard associated with additional controls.

In these evaluations of risk, a risk analysis unit (RAU) approach is used. In this approach, chemicals are grouped into classes based upon their occurrence in waste streams and their biological, physical, and chemical characteristics. Each RAU is then analyzed to determine the health and environmental risks of the entire group. The research program will determine which RAUs are insignificant and need minimal attention, and which RAUs constitute a potential hazard and, therefore, must be more intensively considered in the risk analysis process.

Major research areas include:

- Continued development of models for predicting the transport, transformation, and concentration of synthetic fuel pollutants.
- Evaluation of the impact of synthetic fuel pollutants and their by-products on terrestrial and aquatic food chains.
- Evaluation of exposure and human effects to develop dose-response functions for carcinogenic and reproductive risk analysis.

- Documentation of environmental/human health impacts for synthetic fuel pollutants as determined from occupational or ambient exposures. Major planned research products include:
- Transport and effects of synthetic fuel pollutants in aquatic systems, 1984
- Atmospheric transformation rates and products of major synthetic fuel pollutants, 1985
- Generic assessment providing updated health and environmental risk analyses for coal gasification, coal liquefaction, and oil shale technologies, 1985
- Uptake and transfer of synthetic fuel pollutants in plant/animal food chains, 1986
- User's guide for health and environmental risk analysis methodologies involving complex mixtures, 1986
- Health assessment of production-scale synthetic fuel plant in Yugoslavia, 1987
- Environmental and health assessments of various oil shale, 1987, coal gasification, 1988, and coal liquefaction technologies, 1989

Synthetic fuel pollution reduction: What control techniques are most promising for reducing pollution from synthetic fuels?

Each synthetic fuel production process has its own pollution output, which may be discharged to air, water or land. Different pollutants require both different degrees and types of control and there are numerous control options from which to choose. Before deciding on a set of emissions reduction technologies at a plant, a comparison of control alternatives will help to meet emissions limits at the least cost.

EPA's research program stresses the evaluation of existing synthetic fuel pollutant control technologies for performance, reliability and cost trade-offs. A minor effort will investigate a novel technique for difficult, high-cost clean-up problems. Data will continue to be collected from pilot-scale plants. Data from operational commercial-scale plants will serve to validate the earlier data.

With regards to oil shale, EPA's research will emphasize on-stream testing and evaluation of air and water treatment technologies to establish performance and cost information. Stretford and ammonia or caustic scrubbing will be evaluated for control of sulfur emissions while conventional physical/chemical processes will be tested on actual retort wastewater streams. Research will be initiated to evaluate the concepts of controlling sulfur through adsorption onto spent shale. Research will also be initiated to evaluate the environmental implications of co-disposal of wastewater with spent oil shale.

With regard to coal, EPA-sponsored research will test new methods for removal/recovery of sulfur species (COS,

H_2S, CS_2) from synthetic fuel gas streams. Wastewater treatability studies are focused on post-biological treatment. The data is also being used to provide environmental engineering support to the regions and states on environmental impact statements, permit reviews, and environmental monitoring plans.

Major planned research products include:

- Coal-related sulfur clean-up technology and wastewater treatability report, 1984
- Control of sulfur emissions from oil shale retorting, 1986
- Assessment of oil shale wastewater pollution control technology, 1986
- Design manual for oil shale solid waste disposal sites, 1986
- Performance evaluation of pollution controls at several commercial plants, 1988
- Interpretation reports on monitoring data for regulated and unregulated synfuels plants, 1988

Combustion generated pollutants: How do boiler conditions influence key pollutant-related reactions?

Complex and subtle physical and chemical reactions take place in the combustion and heat release zones of boilers. Boiler manufacturers and operators have studied these reactions extensively in the past with an eye toward improving the energy efficiency of the boilers. Conventional combustion systems are fired chiefly with the fossil fuels: coal, fuel oils, and natural gas. The fuels, due to their differences in physical (solid, liquid, or gaseous) state and composition, behave quite differently during the reactions in which they combine with the oxygen in combustion air to release their energy as heat. These reactions are now being studied to optimize the control of combustion-generated pollutants, such as NO_x and SO_x, while at the same time attaining high energy efficiency.

A fuller understanding of the reactions which occur during combustion, especially those involved in the formation or destruction of pollutants (e.g., NO_x), will enable scientists to understand the cause-and-effect relationships. This knowledge can then be used to identify effective pollutant control approaches and to develop engineering data and designs for low-pollutant systems.

EPA scientists and engineers have been addressing a number of questions about the fundamentals of combustion. Much valuable scientific information has been generated, especially with regard to the control of nitrogen oxides. The recent identification of several combustion process changes offering the potential for significant advances in NO_x control has been an outgrowth of the earlier fundamental combustion research. This has led to an increased emphasis on NO_x control approaches based on (1) precombustor technology and on (2) in-furnance NO_x reduction (through the use of a secondary combustion zone). Most combustion processes emit about 95 parts of nitric oxide (NO) for each 5 parts of nitrogen dioxide (NO_2), these being the principal NO_x species of concern at present. During combustion, NO_x is formed by two mechanisms. First, reactions between nitrogen and oxygen in the combustion air can lead to formation of NO_x. This is referred to as "thermal NO_x" since its formation is strongly dependent on peak flame temperature. EPA research has shown that combustion modifications which lower the peak flame temperature can effectively reduce thermal NO_x emissions.

When the fuel itself contains nitrogen, a second NO_x formation mechanism producing "fuel NO_x" is possible. For coal, which contains significant levels of nitrogen (0.5. to 2.0 percent by weight), and for some residual fuel oils (0.2 to 0.9 percent nitrogen by weight), fuel NO_x is the dominant pathway to NO_x emissions.

As the fuel-bound nitrogen is released from a burning coal particle or an oil droplet, it has two potential ultimate fates; it may be oxidized to form polluting NO or it may be further reduced to form harmless nitrogen (N_2). EPA-sponsored research has shown that formation of N_2 is favored by limiting the amount of free oxygen available during the early stages of the combustion process. Combustion modifications to accomplish that goal are broadly referred to as "staged combustion." The major goal of EPA's NO_x reduction research is development of the technology for new low-NO_x burners which may either be retrofitted to existing boilers or incorporated into new designs. These burners reduce NO_x by delaying the rate of mixing between fuel and air, thereby limiting the availability of free oxygen in the initial burning process. First generation burner technology employing this principle has already been incorporated into commercial practice.

EPA research strategy is to continue to obtain the information needed to optimize control technologies for the combustion of both coal and heavy fuel oils. For coal, the mechanisms and rates associated with the volatilization of sulfur species from the fuel particle matrix will be determined. For fuel oils, the role of droplet size and volatilization of the fuel droplets during mixing with the combustion air will be determined. For both fuels, the role of in-furnace $N0_x$ reduction by the introduction of a secondary fuel beyond the primary combustion zone will be investigated.

In addition, new studies will be initiated to investigate thoroughly the use of precombustor technology as a means of drastically reducing NO_x emissions while simultaneously controlling particulate and SO_2 emissions. The research emphasis initially will concentrate on optimizing the applications of low-NO_x burners for coal and for oil. Later, the emphasis will be shifted to investigate and maximize the effectiveness of infurnace NO_x reduction and precombustor technologies for utility and industrial boiler applications.

Major planned research products include:

- Determination of the rates and mechanisms associated with volatization of sulfur species from coal, 1985
- Performance optimization and evaluation of industrial boiler low-NO_x heavy oil burners, 1985
- Demonstration of the performance optimization of low-NO_x coal burners for utility boilers, 1987
- Evaluation of the use of in-furnance NO_x reduction for industrial boilers, 1988

Long Term Trends

While this report is focused upon EPA's research strategy for the next five years, it would be incomplete without some reference to the long-term trends which shape the context within which our research strategy evolves. In the following, we identify a few of the major environmental issues likely to affect the implementation of energy technologies between now and the year 2000. In identifying these issues, we include the following elements.

First, the issues we choose span most energy technologies, but focus on coal combustion and the synthetic fuel (coal and oil shale) technologies. It is our belief that it is in these areas where most of the energy-related environmental impacts could occur.

Second, the issues cover a range of goals such as long-term protection of climate, water availability and quality, human health and pristine environments.

Third, most of our issues represent a departure from the classical issues which have received the attention of public and regulatory bodies in the past. For instance, we focus on overall solid waste disposal rather than limiting attention to air or water. We also anticipate greater attention to carcinogens and toxics in all media. Further, our long-term issues often differ from classic environmental analyses in that they are truly multimedia in nature (e.g., trace elements released to land, air, and water).

Fourth, the solutions to many of the issues will tend to be in conflict with the solutions of others. For example, the health effects of deep mining can be reduced by turning to surface mining (which, in turn, exacerbates the problems of water availability, ground water quality, land use, trace elements, and pristine environments in the West).

Fifth and finally, unlike the classic issues where the public could see a polluted stream and demand it be cleaned up, the level of controversy and resolution of controversy are directly related to the state of knowledge and research.

Keeping the above perspective in mind, the following are important energy-related environmental issues which we expect will shape EPA's research program for the next two decades. These issues may significantly impact the implementation of an energy policy and/or technology.

Solid waste from conventional coal use: The use of coal creates large quantities of solid wastes consisting of ash, tars, chars, slag, scrubber sludge, spent catalysts, fluidized bed media, and biological treatment sludge. Solid wastes can be disposed of in a number of ways, with the major environmental concern being the penetration of leachates into aquifers or surface waters. Because of the toxic nature of some of the components (trace metals, etc.), the disposal of this material may pose a problem for siting and operation of facilities.

Siting of coal conversion facilities: A host of regulations, physical factors, and public attitudes can combine to severely limit the siting of coal conversion facilities. For example, current federal regulations to prevent significant deterioration of air quality in certain areas may effectively limit energy development activities in those areas.

Carbon dioxide buildup: Fossil fuel combustion produces carbon dioxide (CO_2). The ambient CO_2 concentration has been increasing throughout the troposphere. This increase may cause climatic changes and increase the surface temperature of the earth.

Offshore oil: There are four major environmental concerns with regard to outer continental shelf (OCS) oil development: water/oil contamination, air pollution (NO_x, SO_x and hydrocarbons), aesthetics, and the impacts of ancillary onshore facilities.

Trace elements: Trace elements are emitted by most energy technologies and are found in the products as well as the solid, liquid, and gaseous waste streams. The increasing use of coal will magnify this problem. Long-term, low-level trace element exposure will have uncertain human health and environmental effects.

Groundwater: Groundwater contamination through deepwell injection, solid waste leaching, and *in situ* coal and shale processing will be of increasing concern in regard to toxic organic and inorganic chemicals. The commercialization of *in situ* coal gasification and *in situ* and surface oil shale retorting demands a fuller understanding of these technologies and their effects on groundwater and water supplies.

Fugitive emissions: Gaseous emissions or leaks may occur from coal gasification and liquefaction plants because of improper equipment design and/or maintenance. Such emissions may include numerous sulfur and nitrogen compounds, trace elements, and aliphatic and aromatic hydrocarbons. The main concerns are potential carcinogens, synergisms and undetermined effects of the various compounds emitted.

Fine particles: The total atmospheric loading of fine particulates results from emissions of primary fine particulates from natural and other sources (especially fossil-fuel technologies) and from the secondary fine particulates formed from chemical reactions in the atmosphere. Fossil energy development may increase, or change the nature of, airborne fine particulates, thus causing both human health and environmental impacts.

Radioactivity from coal: Radioactivity in coal stems primarily from the natural decay series of radionuclides U238 and Th232. Concentrations of these radionuclides vary widely from the national average of 1.8 ppm uranium and 4.7 ppm thorium. Increased exposure to ionizing radioactivity induces carcinogenic and mutagenic responses.

Nitrogen oxides: Fossil fuel combustion is the major source of anthropogenic nitrogen oxide emission. NO_x plays an important role in visibility reduction, human health hazards, damages to vegetation and material, and acid deposition.

Land disturbance from surface mining: The principal environmental concerns associated with large-scale surface mining are: maintaining original topography and high quality of water supply; preserving local ecology; and agricultural productivity.

Biomass energy exploitation: Conversion of biomass is a solar technology which may have significant environmental impact. The major sources of biomass are terrestrial and marine plant life. Conversion processes which use biomass (from both plant and animal sources) are potentially significant environmental concerns.

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Acid Rain

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Sources/receptors: What are the quantitative relationships between emissions sources and deposition receptors?

Loadings/effects: What are the quantitative relationships between acidic deposition loadings and their effects?

Trends: Has acidic deposition been increasing?

Liming: Is liming of acidified lakes environmentally sound and economically feasible as a mitigation measure.

7 Acid Rain

Introduction

The term "acid rain" means the atmospheric deposition of acidic or acid-forming compounds in either their dry or wet form. These compounds exist in the atmosphere as gases or aerosol particles. The gases of concern are sulfur dioxide (SO_2), nitrogen oxides (NO_x) and hydrogen chloride (HCL). The aerosol particles are sulfuric acid, nitric acid (a gas in the troposphere) and certain sulfate and nitrate compounds. While scientists generally agree that these compounds are responsible for deposition of varying degrees of acidity, there remain major uncertainties regarding the causes, extent, consequences and cures for the problem.

The major scientific issues are:

- What source/receptor relationships should be used to determine emission control strategies? To compare deposition from local sources with deposition transported from distant sources? To determine the importance of acid aerosols from natural sources?
- What are the quantitative relationships between acidic deposition loadings and their effects?
- Has acidic deposition been increasing?
- Is liming of acidified lakes cost-effective?

To answer these questions and to provide the scientific and technical data that regulators and legislators need for formulating policy, EPA and other federal agencies are conducting a major research program.

EPA's program is investigating: the relationships between man-made emissions, precursors, and acidic deposition; the processes influenced by the formation and transport of acidic and acidifying substances; the deposition of acidic substances on terrestrial and aquatic systems; and effects of acidic deposition on aquatic environments, drinking water, agriculture, natural terrestrial ecosystems, and materials. The program will provide assessments to support policy analyses that determine the cost effectiveness of potential control strategies.

The acidic deposition research program for fiscal year 1984 is allocated $15.4 million, which is part of the $27.6

million budget of the Interagency Task Force on Acid Deposition. EPA's resources are divided among the programmatic categories of the interagency task force as follows: man-made sources, \$1.3 million; atmospheric processes, \$5.3 million; deposition monitoring, \$1.9 million; aquatic impacts, \$3.0 million; terrestrial impacts, \$1.5 million; effects on materials, \$0.6 million; and assessments and policy analysis, \$1.8 million.

Legislative Mandate

EPA's program is a component of, and operates in cooperation with, the National Acid Precipitation Assessment Program (NAPAP), established by Congress in 1980 under the Energy Security Act. Management of the NAPAP research is being handled by the Interagency Task Force on Acid Precipitation, which is jointly chaired by EPA, the Department of Agriculture and the National Oceanic and Atmospheric Administration, and includes research representatives from those agencies and from the Departments of Interior, Health and Human Services, Energy, Commerce, State, the Council on Environmental Quality, the National Aeronautics and Space Administration, the National Science Foundation and the Tennessee Valley Authority. The federal research program has a ten-year legal mandate. It oversees all federally funded acidic deposition research projects. EPA has a coordination role in the task groups for aquatics, control technology, and assessments and policy analysis. EPA also has a major research program to study man-made acidic deposition sources, atmospheric processes, deposition monitoring and terrestrial and materials damage.

Background

Acidic deposition has most likely occurred in cities for several centuries. It was first described by Robert Angus Smith in Manchester, England, in 1853. In the United States, acidic precipitation below a pH of 5.0 (snow, sleet, rain, hail) has been measured over a large portion of the eastern states for the past 25 years.

The formation of acidic deposition begins when atmospheric SO_2 or NO_x, as either gases or liquid droplets, are oxidized by other airborne chemicals to become sulfate and nitrate aerosols or gaseous nitric acid. While these atmospheric transformations are thought to account for the majority of the acidic compounds, some acidic aerosol particles are emitted into the air directly from power plants, automobiles and other man-made sources.

Once formed, acidic gases and aerosol particles can be removed from the atmosphere by either rain, snow or fog, resulting in acidic precipitation. Such atmospheric removal processes are referred to collectively as "wet deposition." If there is insufficient moisture for precipitation to occur, the acidic compounds including SO_2 and NO_x not oxidized to aerosol particles, can settle or diffuse to the earth and be deposited in a dry form, eventually oxidizing or combining with water (and also oxidizing) to produce sulfuric or nitric acid. This phenomenon is called "dry deposition."

Atmospheric SO_2 and NO_x come from man-made emissions as well as from natural sources. The chemicals which serve as efficient oxidizing agents in the atmosphere primarily are believed to come from photochemical reactions involving volatile organic compounds (VOCs) and NO_x, and, possibly, hydrogen peroxide (H_2O_2).

Estimates of man-made SO_2 emissions show that 65% of U.S. emissions come from electric utilities and the remainder from various industrial and transportation sources. Estimates of man-made NO_x emissions in the U.S. indicate that more than 40% come from transportation sources, 30% from electric utilities and the remainder from other types of combustion. The primary man-made sources of volatile organic compounds are automobiles, processes that use solvents, and facilities for fuel production and distribution.

The natural sources of atmospheric sulfur compounds include marine bioactivity, swamps, and volcanos. Estimates of the sulfur compound emissions from these sources are comparable to those for man-made sources on a global basis, although man-made processes are responsible for the dominant portion of SO_2 emissions in industrialized areas such as eastern North America.

Estimates of global NO_x emissions from natural sources (microbial activity in soils, burning of forests and agricultural residues, and lightning) are much less certain than are the SO_2 estimates. Current global estimates indicate natural NO_x emissions to be of the same magnitude as emissions from industrial sources. For the United States, however, industrial NO_x emissions are roughly estimated to be ten times greater than natural emissions.

The amount of volatile organic compounds emitted from natural sources is also uncertain. The role of natural emissions in the regional formation of oxidizing agents may or may not be significant.

Whether natural or man-made, all acid-forming compounds and aerosols can be atmospherically transported for distances of a few to many hundreds of kilometers from their point of release to where they return to earth as wet or dry deposition. If deposited in the sea, the acidic aerosols and acid-forming compounds are neutralized, and the loadings are small compared to the normal ionic concentrations of seawater. If deposited on land, the compounds may or may not cause an adverse effect, depending upon the nature and sensitivity of the receptor site.

The effects of acidification on aquatic life have been demonstrated in the field. However, the extent to which these effects are caused by acidic deposition has not yet been rigorously determined. Quantification of these and other effects on susceptible lakes and streams is currently under investigation.

Aquatic effects can manifest themselves as changes in the life forms found in the water. Fishless lakes, for example, can occur when a lake's pH falls below 5 (note: the lower the pH, the greater the acidity; a pH of 7 is neutral). Several scientific studies conclude that a number of lakes in North America may have been affected by acidic deposition.

Acidic deposition may also affect forests, crops, soil systems, drinking water, man-made materials and, indirectly, human health. Scientists are now seeking to determine quantitatively whether and to what extent such effects occur. Because of the complexity of the natural systems involved, however, decisive answers are difficult to come by. For example, after more than a decade of investigations, Scandinavian researchers still find it difficult to demonstrate conclusive cause-and-effect relationships between acidic deposition and forest productivity.

Studies of acidic deposition effects on natural terrestrial ecosystems have shown limited evidence of damage. While acidic deposition may subtly influence the functioning of terrestrial ecosystems, potentially harmful effects may be obscured in the short term by nutrient enhancement from sulfates and nitrates. Recently, however, declines in the productivity of some forest systems have been noted, although the cause for the declines remains unclear. Therefore, a primary concern for research study is the long-term implications of acidic loadings to natural systems.

Some studies have demonstrated that acidic deposition either increases or decreases crop yield. Nutrient enhancement, again, tends to cloud the issue. Because plant responses to acidic deposition (in either natural or managed systems) depend on many variables such as soil condition, species sensitivity, life stage, other air pollutants, and drought, no major damage to plant productivity has been specifically attributed to acidic deposition. Some researchers theorize that responses to acidic deposition may be occurring but that the responses are being masked by the complexity of the affected ecosystems.

The direct risk to humans from acidic deposition is believed to be very low. The pH of acidic deposition is generally well within the range normally tolerated by human skin and gastrointestinal tracts. Indirect risks to humans which might come from drinking water and food contaminated by acidic deposition are also quite low, except where untreated cistern or well water is used. For example, while acidification of plumbing pipes can cause lead and copper to leach into cisterns, untreated well water, and drinking water, most urban and municipal water systems control pH levels to reduce such corrosion. Surveys will indicate whether pH is a problem in smaller systems.

Acidification can also release heavy metals such as mercury and cadmium from lake and stream sediments making them available for uptake by fish. These heavy metals, it is theorized, may accumulate in fish tissues which may, in turn, be consumed by humans. Although such effects could occur, current evidence does not indicate that acidic deposition is a human health problem.

Among the many research projects that are part of the federal acidic deposition research program are several that address the entire range of acidic deposition issues. Two such projects are part of EPA's program. The first involves production of a major report summarizing the state of scientific knowledge with regard to all aspects of acidic deposition. These critical assessment review papers were published in 1983. The second project involves completion of an integrated cost-benefit assessment framework for linking emissions models, atmospheric models, and effects relationships. This framework, intended for use in policy-related studies, will be available in 1986.

Major Research Topics

Source/receptor: What are the quantitative relationships between emissions sources and deposition receptors?

The atmospheric chemistry processes that form acidic deposition are being studied in order to develop source/receptor relationships. Through mathematical modeling and other means, quantification of atmospheric processes will help scientists to understand several key factors. For instance, scientists know that the presence or absence of certain oxidants, other chemicals, moisture, and particulates influence the conversion of SO_2 and NO_x to atmospheric acids, but the complex interactions of all these elements have yet to be unravelled. Likewise, ozone and hydrogen peroxide are known to play a significant role in the formation of oxidants, but their exact effect on the rate of conversion has yet to be determined.

Another major requirement for defining source/receptor relationships is the identification and measurement of factors that control atmospheric transport of acid-forming compounds and aerosols. The intricacies of meteorological mechanisms, which are just beginning to be understood, make it difficult to specify the atmospheric paths along which compounds may be transported.

As part of EPA's research effort, large-scale meteorological models are being refined. One current shortcoming is that the models assume that the rate of conversion of sulfur and nitrogen compounds to acidic compounds is proportional to their respective atmospheric concentrations — in other words, the more SO_2 present in the atmosphere, the more acid sulfate produced. Theory and experimental evidence show that this assumption may be too simplistic to describe actual photochemical conversion rates. Because of this, models are now being improved to include the influences of the mix of oxidants, chemical competition for oxidants, and the presence of aerosols and particulates to act as reaction sites. The refined models will also reflect more accurately the vertical transport of compounds between various layers of the atmosphere. Horizontal transport rates, and hence the extent of dispersion, depend in large measure upon vertical exchange rates.

Another problem with using existing models to differentiate between deposition from local and long-range sources is that calculations for sulfur compound deposition are far more developed than are those for nitrates. In some areas, locally produced nitrogen oxides may make an important contribution to acidic deposition.

Finally, long-range transport models only indicate the aggregate contribution of emissions from geographic areas; they do not indicate those from individual sources or types of sources. Thus, the models cannot differentiate among emissions from utilities, industries, homes, or automobiles. Until refined to do so, their usefulness, especially in formulating and testing control strategies, is limited.

In 1983 EPA, NOAA, DOE and TVA began field studies and the development of better atmospheric models to provide more information about long- and short-range acidic deposition transport, and the relative importance of wet and dry deposition. An inventory of acid deposition precursor emissions data will be developed to support the modeling research. Model data will also help to determine oxidation reaction pathways and atmospheric oxidant concentrations.

Building upon the results of this research, numerical transport models are expected to demonstrate improved source/receptor associations. The research will include models for examining long-range transport and regional aspects of acidic deposition, and a comprehensive field study of source/ receptor relationships using atmospheric tracers. These results will be available in 1986 and 1988.

Among the other major planned research products include:

- Electric utility simulation model for emissions forecasting, 1985
- Comprehensive emission inventory system, 1985
- Industrial simulation model for emissions forecasting, 1985
- Define the relative importance of deposition from local sources, 1986

Loadings/effects: What are the quantitative relationships between acidic deposition loadings and their effects?

By studying the physical, chemical, and biological characteristics of lakes, streams and watersheds, and the relationships between amounts of acidic deposition in a watershed and the pH levels in an aquatic ecosystem, EPA research seeks to quantify the relationship between acidic deposition loadings and ecosystem effects. One of the main problems facing this effort results from extreme local variations in the buffering capacity of watersheds.

The buffering capacity of a lake and its watershed determines the lake's ability to neutralize acidity. Sensitive aquatic systems have watersheds with little or no neutralizing capability in the soils and bedrock. As a result, such systems have insufficient means to neutralize incoming acids. Such sensitive areas are generally mountainous, with shallow soils underlain by granitic bedrock. Such areas include portions of New York, the New England states, the Appalachians, the Ozarks, the Rockies, Sierras, Cascades, the provinces of Ontario, Quebec and Nova Scotia, and mountainous areas in western Canada.

Buffering capacity varies with the nature of the underlying rocks, surrounding soils, and vegetation in the watershed. Lakes in watersheds with low buffering capacity may become acidified, while lakes in the same region with watersheds having a higher buffering capacity, may not. The Adirondacks, southern Ontario and Nova Scotia are the main regions where some lakes show the greatest effects from acidity. In addition, areas of the Southeast and Upper Midwest are also sensitive to acidic inputs due to the poor buffering capacity of the soils in these regions.

Many lake features influence susceptibility to acidic deposition. A lake's size and depth, its rate of "flushing" (water flow-through) and whether it is fed by surface water or ground water all help to determine how it responds to acidic deposition. Lakes that are poorly buffered are particularly susceptible to surface water inflows with low pH's. Surface water with a low pH can be caused by acidic deposition, land use practices, natural "humic" processes, or a combination of all three. A dramatic decrease in a lake's pH can occur in the spring when acids accumulated in the melting snow flow into a lake. This episodic phenomenon, known as "spring shock," can deplete fish populations. Weather patterns also play a role. Local air turbulence and eddys of rain and snow over hills and mountains contribute to the local variability of acidic deposition impacts.

The manner in which land is used in watersheds is an important factor contributing to potential lake acidification. Logging causes a dramatic shift in an ecosystem's nutrient cycling. Around populated lakes, effluents from residences may neutralize some lake acidity.

To determine the extent and magnitude of lake and stream acidification and the associated loss of commercially important fish, the EPA, the Departments of Interior, Agriculture, and Energy, the Tennessee Valley Authority, industry, and several states are cooperating in a major research program. One goal of the program is to develop a national inventory of the impacts of acidic deposition on the quality of surface waters, including drinking water. In 1983 this program produced regional and national tabulations and maps showing the distribution of acidified, and acid-sensitive waters. By comparing historical water quality data with watershed studies, the research will assess the rates of change in water chemistries and thus provide information for evaluating future water conditions. To augment this data, the EPA's National Lake Survey program is being expanded. This program provides an accurate record of actual conditions in a large number of lakes over a wide geographic area. As part of the National Lake Survey program, field surveys will be added in 1984 to inventory the biological impact of acidification on fish.

Correlations among research results will help to reveal the causes, as well as the extent, of altered aquatic systems. A major assessment of atmospheric deposition loading limits for aquatic ecosystems effects will be published in 1985. Reports to assess damages to aquatic ecosystems in physical and economic terms will be published in 1986 and 1988. Another assessment, this one of terrestrial effects in economic terms, is scheduled for 1985 with updates in 1987 and 1989.

Trends: Has acidic deposition been increasing?

Regardlesss of where acidic deposition has been observed and measured, there is insufficient evidence to accurately define long-term trends. Historical data on rain acidity are simply too meager. Historical records about U.S. air quality are also inadequate for establishing scientifically rigorous trends regarding atmospheric acidity or the concentrations of precursor chemicals. In this case, there is a need to understand natural cycles, or geocycles, to avoid misinterpreting "apparent" short-term trends.

In Scandinavia, where acidic deposition data records are more complete than in North America, analyses suggest further complication. Strong correlations found between the concentrations of sulfates and nitrates in precipitation and precipitation acidity are not reproducible when sulfur emissions data are collected from arrays of monitoring stations over extended time intervals. The differences in correlation between concentrations and emissions may reflect year-to-year variations in atmospheric transport patterns or the complexity of atmospheric mechanisms.

EPA and other federal agencies are currently gathering data to determine acidification trends. Effects studies include the examination of tree rings, lake sediment cores, acidification damage to tombstones, and an analysis of historical acidity measurements. To gather precipitation data, EPA participates in the National Trends Network (NTN) which will soon have 150 precipitation chemistry monitoring sites in the U.S. Presently, EPA also contributes to the National Atmospheric Deposition Program (NADP), a federal, state, and private program that operates 110 monitoring sites, many of which will become part of the NTN. EPA is also cooperating with other agencies in initiating a research program to quantify dry deposition loadings in the U.S.

An assessment of forest effects from acidic precipitation using tree ring analysis is due in 1984.

Major planned research products include:

- Updated evaluation of dry deposition measurement techniques, along with recommendations for monitoring network designs, 1985
- Trends related to acidic deposition, 1985

Liming: Is liming of acidified lakes environmentally sound and economically feasible as a mitigation measure.

One suggested method for protecting and restoring susceptible lakes is to add lime to neutralize the acids. Studies of Swedish lakes and streams demonstrate that adding lime to the water restores fish habitats, enables restocked fish to survive and reproduce, and causes undesirable plant species common to acidic water to disappear. However, the protection of lakes continuing to receive acidic inputs would require periodic reliming.

The Fish and Wildlife Service (FWS) of the Department of Interior in conjunction with EPA, will conduct field research on lake liming in the Adirondacks and Maine. Liming strategies to protect against "spring shock" and to trap metals in the watershed before they enter streams, are being tested. Additional liming research is being conducted by the private sector and by Canada. The FWS is also working closely with the Electric Power Research Institute in intensive studies of liming.

These research activities will identify where liming is practical and will quantify both beneficial and adverse effects. A report on the economic and biological feasibility of liming as a mitigation measure will be produced in 1984. Final recommendations on the use of liming will be made in 1986. Among the major research products associated with this issue is the publication of a cost-benefit assessment of acidic deposition mitigation strategies. This assessment will be published in 1987 and updated in 1989.

will be made in 1986. Among the major research products associated with this issue is the publication of a cost-benefit assessment of acidic deposition mitigation strategies. This assessment will be published in 1987 and updated in 1989.

8 Drinking Water

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Drinking Water

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Major Research Topics

Distribution system: How do drinking water distribution systems contribute to health risks, costs and compliance?

Disinfection by-products: What methods are needed to isolate, identify and determine the health hazard of the byproducts of drinking water disinfection?

Infectious disease: What data and methods are needed to assess the role of drinking water in infectious disease transmission?

Health risk assessment: How can risk assessments of human exposure to chemicals present in drinking water be improved?

Long Term Trends

8 Drinking Water

Introduction

State and local governments have the main responsibility for drinking water quality. Demands on the water supply are increasing while, at the same time, chemical contamination of water sources is a major problem in some locations. Water management decisions are becoming both more complicated and more difficult.

State governments need help in addressing major problems related to drinking water quality. State government decision-makers are especially concerned about revisions of the National Interim Primary Drinking Water Regulations (NIPDWR) due in 1984-1985, when new regulations for a variety of synthetic and volatile organic chemicals will also be considered. Additional scientific data are also needed to support development of other new regulations and Health Advisories. For example, disinfectants and disinfectant byproducts, as well as safe alternative disinfectants, must be evaluated.

Legislative Mandate

The Safe Drinking Water Act (SDWA), P.L. 93-523, as amended, requires EPA to establish drinking water regulations to protect human health and welfare. The NIPDWR fulfill the requirement to protect human health by specifying maximum chemical and biological contaminant levels (MCL) allowable in drinking water.

The Safe Drinking Water Act also grants EPA the responsibility and authority to conduct drinking water research. Section 1442 of the SDWA specifically authorizes EPA to engage in research concerning: the occurrence and health effects of chemical and biological contaminants in drinking water, the analytical procedures for monitoring contaminants, the applicability of treatment technologies, the protection of underground drinking water sources and the exploration of scientific questions of emerging problems.

Background

The primary goal of this EPA research program is to develop the scientific and technical data needed to assure safe public drinking water systems and to protect groundwater resources. Much of the drinking water research program provides information used by state and local water authorities or by EPA itself to develop changes to drinking water regulations.

In this context, EPA's health effects research is especially important to both the development of federal drinking water maximum contaminant levels and to develop information that can be used to develop Drinking Water Health Advisories that assist states in dealing with contamination incidents. Since groundwater may be affected by hazardous waste disposal practices and the use of pesticides, this topic is discussed elsewhere as a "cross-cutting" issue.

The drinking water research program for fiscal year 1984 is allocated $23.8 million. These resources are distributed among the research disciplines as follows: health effects, 39%; engineering and technology, 29%; environmental processes and effects, 20%; monitoring systems and quality assurance, 10%; and scientific assessment, 2%.

Major Research Topics

EPA's drinking water research program will continue to provide support to the EPA Office of Drinking Water in developing revised and new Maximum Contaminant Levels (MCLs) and Health Advisories, and to states in their implementation of safe drinking water programs. Quality assurance and monitoring methods development will continue to be a high priority as well. For this year's *Outlook*, we consolidated the research topics discussed to focus attention on only the most important topics in drinking water research. As a result, the issues discussed below do not, by any means, cover the entire research program. For example, work will be continuing to examine treatment alternatives; however, the contribution of distribution systems to health risks, costs and compliance is an area where increased effort will be required. Therefore, we have narrowed the issue to focus on distribution, and have chosen not to discuss other technology evaluation work which is ongoing and is relatively better understood. Likewise, in the health area, we have chosen to focus on the broadest and most critical issues of health risk extrapolation and infectious disease transmission and not to discuss work on specific chemicals or metals. And, finally, most of the discussion of groundwater monitoring and assessment has been shifted to the "Cross cutting issues" chapter.

Distribution system: How do drinking water distribution systems contribute to health risks, costs and compliance?

Water delivery systems can have a definitive effect on the quality of water received at the tap. For example, 20 percent of the waterborne disease outbreaks in the United States are caused by failures in the distribution systems. *Legionella*, the causative agent of Legionaire's Disease may survive in some water distribution systems, and excessive amounts of lead from distribution system pipes has been found in some tap water samples.

These problems exist in both large and small and old and relatively new water systems. Coupled with these water quality considerations is the fact that delivery systems account for 80 percent of the cost of water supply.

Older urban systems contain thousands of miles of pipelines. Pipeline failures and resulting loss in system pressure are a growing hazard to streets and property, to human health, and to commercial and industrial water users.

Little systematic information is available concerning the water quality deterioration that can take place in drinking water delivery systems. Less is known concerning the factors that affect the repair and replacement requirements for the pipe network itself. Preliminary studies indicate that significant water quality problems do exist in distribution systems and that there are quantifiable interactions between quality and operational problems. For example, tubercule build-up in distribution system lines not only reduces water quality but can also restrict hydraulic capacity thus increasing operating costs and interfering with service.

There are four major areas where gaps in our scientific knowledge are interfering with effective management of drinking water distribution systems. These are:

- identification and analysis of organic, inorganic and microbiological contaminants;
- inadequate data on the relationship between treatment strategies and consequent deterioration of water quality in the distribution system;
- insufficient data on the factors causing deterioration of water quality within the distribution system itself; and
- problems with bringing small systems into compliance.

Deterioration of water quality during distribution can occur because of inadequate treatment and disinfection techniques that result in the formation of disinfection byproducts, internal corrosion, leaching of contaminants from storage and distribution components, and bacterial regrowth within the system. Information needs include the following: factors affecting deterioration of water quality in distribution systems and risks to human health, factors affecting failure rate in distribution systems, models to permit timely anticipation and detection of failures and to link the quality and cost and operational variables in distribution systems, and techniques for managing and tracking the quality and costs associated with delivery systems.

EPA's research role is primarily in terms of its responsibility for developing scientific data on the phenomena associated with water quality deterioration in distribution systems. EPA researchers work directly with institutions such as the American Water Works Association to provide information on compliance strategies for drinking water utilities.

With regard to the four major information gaps mentioned above, our research strategies are:

Organic,inorganic and microbiological contaminants: EPA research is attempting to identify the specific characteristics, extent and health significance of reaction byproducts from drinking water disinfectants. Laboratory work will define the extent and character of reactions with aquatic humic materials and the nature of organic halogens and oxidation by-products that are formed. The physical and chemical factors that influence the reactions will be identified.

Laboratory work to characterize the reaction by-products is now underway. Preliminary treatment data focusing on the amounts of organic halogens produced are being collected from bench and pilot studies. Treatment method effectiveness data will be developed later. Should the health effects research indicate a health problem, evaluations will be made at full-scale treatment plants.

Treatment strategies/deterioration relationship: By 1985, EPA investigators will have evaluated all major disinfection processes in laboratory and field tests. Other research will provide data on improving treatment technologies, including disinfection, microbe filtration, ion exchange, aeration, adsorption, and/or reverse osmosis for the control of organic, inorganic and radionuclide chemicals, chlorinated organics, and/or particulates. Bench, pilot and field studies will be conducted to define the interaction between treatment strategies and water quality deterioration in distribution systems.

Overall system integrity: The persistence and potential regrowth of organisms in distribution systems is influenced by a variety of conditions that include physical and chemical characteristics of the water, system age, variety of pipe materials and the availability of suitable sites for bacteria colonization. Laboratory and field studies will be conducted to evaluate the impact of changes in treatment and disinfection practices brought about by existing and new regulations. Investigations will also be carried out on other key factors that influence microbial regrowth, including nutrients, temperature, and protective habitats such as sediment accumulations.

In addition, theoretical, laboratory, and field studies will be conducted to define the factors associated with distribution system repair and replacement criteria. The costs associated with optimal renovation strategies will be identified.

Small system compliance problems: Research is evaluating the cost and engineering feasibility of specific treatment techniques to remove or control problem inorganic contaminants (such as arsenic, radium, and uranium), organic contaminants (including pesticides and chlorinated organic solvents), trihalomethanes, microorganisms and particles. Several evaluations will be at pilot-or full-scale. Bench-scale studies are being done to define variables that govern the effectiveness and efficiency of treatment processes prior to large-scale evaluations. Reports of these findings will be released beginning in 1984 and continuing into 1987.

Major planned research products include:

- Evaluation of effects of water quality on corrosion of pipe materials, 1985

- **Techniques for measuring repair, renovation, and replacement needs in distribution systems, 1985**
- **Characterization of treatment techniques for newly recognized waterborne pathogens, 1986**
- **Methodology for control and monitoring of disinfection by-products, 1987**
- **Evaluation of chemical, microbiological and economic factors affecting the operation of water distribution systems in small communities, 1987**
- **Evaluations of THM control using alternative disinfectants and treatment modifications, 1988**
- **Cost and performance data on alternative control strategies, 1988**
- **Infrastructure needs for drinking water systems, 1989**

Disinfection by-products: What methods are needed to isolate, identify and determine the health hazard of the by-products of drinking water disinfection?

Trihalomethanes were the first recognized by-products of chlorination of drinking water. It is now clear that a variety of other potentially carcinogenic and mutagenic chemicals, such as the haloacetonitriles, halogenated aldehydes, ketones, and a number of as yet unidentified by-products are produced by chlorination. By-products of alternate disinfectants to chlorine are even less well understood. Furthermore, while we do have some data derived from animal tests, the human health implications of these substances in normal measured drinking water concentrations are poorly understood.

In addition to the by-products formed in drinking water, a variety of other substances are produced in the bodies of those who drink the water. Preliminary data indicates that chlorine and chloramine produce low doses of by-products which can increase spermhead abnormalities in mice. Newer data indicates that, under certain conditions, chlorinated drinking water can increase serum cholesterol levels in rabbits and pigeons, suggesting a concomitant increase in the risk of atherosclerosis. Research by EPA seeks to identify disinfection by-products, determine which of these chemicals possess toxicological properties of concern, establish the dose-response relationships for these effects and, ultimately, establish the risk involved with alternative disinfectants.

Major planned research products include:

- **Carcinogenic properties of identified products of chlorine and other disinfectants, 1985**
- **Toxicological studies of identified products of disinfection reactions in water, 1986**

Infectious disease: What data and methods are needed to assess the role of drinking water in infectious disease transmission?

Everyone in this country expects that their tap water will be free from microorganisms that would cause infections in humans. However, each year numerous waterborne disease outbreaks indicate that this is not always the case.

Even though no etiological agent is identified in about half of the outbreaks, the protozoan, *Giardia*, and Norwalk-like viruses are now recognized as major waterborne pathogens. Bacterial agents such as *Legionella* and *Campylobacter* have recently been associated with waterborne disease and, like *Giardia*, may contaminate water from other than human fecal sources. In addition to these known pathogens, common water-or soil-based bacteria may become opportunistic pathogens under certain conditions.

Data are extremely limited regarding the problems with microbial contaminants discussed above. In order to gain an understanding of the importance of these health questions, research will be carried out to develop methods to isolate and identify pathogenic microorganisms in water and host specimens, to determine the infectious dose of known and suspected waterborne agents and, to determine responsible agents. Data obtained from field and laboratory studies will identify situations that pose real and potential problems and provide water authorities and regulatory agencies with methods and data for developing appropriate regulatory strategies.

Major planned research products include:

- Human infective dose of enteric viral pathogens, 1984
- Giardia occurrence in watershed animals, 1985
- Occurrence and significance of infectious agents in drinking water, 1988

Health risk assessment: How can risk assessments of human exposure to chemicals present in drinking water be improved?

Most current regulatory and advisory levels for recognized carcinogens or systemic toxicants in drinking water are based on data from animal studies. This involves extrapolation from high-dose to low-dose and from animals to man, using in many cases such "crude" models as the low-dose-linear nonthreshold extrapolation model for carcinogenic risk. This can lead to underestimations or overestimations of risks.

Risk assessments are further complicated by the fact that drinking water contaminants are usually present in combinations, along with by-products of various disinfection processes for which few toxicological data are available. Furthermore, these contaminants are available to these humans via inhalation and through skin absorption as well as ingestion. Consequently, risk assessment procedures and supporting research studies must be developed which will account for multiple routes of exposure, pharmacogenetic mechanism of action, additive effects (synergistic), and allow for extrapolation from high-dose laboratory data to risk estimates of ambient levels.

Many of these information gaps will be addressed by blending current theories with available toxicity and carcinogenicity data. EPA researchers will begin by developing species conversion models from detailed data on well-studied chemicals. Simplifications will then be applied to produce conversion models based on readily available data (e.g., chemical structure, basal metabolism). The models will be validated by empirical comparisons of toxicity data, across species, for a large number of chemicals.

The influence of known partial lifetime exposure on toxicity or cancer risk will be similarly addressed using models and available data. Known and postulated cellular mechanisms of carcinogenesis will be investigated for concordance with, or further modification of, the current low-dose extrapolation models. Guidelines currently being developed will be applied to the assessment of potential risk from exposure to mixtures of drinking water contaminants. Mixture toxicity will be treated by applying additivity models, comparing the predicted risks to those observed for the few well-studied industrial mixtures, and evaluating the model in terms of low-dose pharmacokinetics. The likelihood of known synergistic chemicals occurring in the same drinking water supply will be estimated by evaluating previous exposure assessments.

Low-dose extrapolation of data on target organ toxicities have been based upon the concept of a threshold. Based upon assumptions about the range of sensitivities in a population and the degree of certainty about the across-species extrapolation of the data, a number of arbitrary safety factors ranging from 10 to 1000 or more are in common use. The validity and range of factors appropriate to across-species extrapolation can only proceed by comparison of animal data to carefully obtained epidemiological data in targets of opportunity where quantitative estimates of exposure can be made.

Low-dose extrapolation models, on the other hand, require a clearer understanding of the processes involved in chemically-induced target organ damage. Secondly, the variation in the sensitivity of these processes within and across species must be established in order to determine the biological limits on the variability of such systems within and across species. Such knowledge is also needed to predict the degree and nature of interactions when drinking water is simultaneously contaminated by more than one chemical that affects the same organ system.

EPA shares interest and information in the risk assessment issue with other federal regulatory agencies — primarily the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA) and the Consumer Product Safety Commission (CPSC). FDA has a substantial research program involving oral exposures. OSHA's interest is primarily in the inhalation route. Other federal basic research facilities are studying the mechanisms of chemical carcinogenesis, but their objectives generally do not emphasize the problem of risk assessment, which is of major concern to EPA and the other regulatory agencies. The problem of assessing health risks of disinfection by-products is specific to EPA.

Major planned research products include:

- Potential exposure to drinking water contaminants via other routes of exposure, 1984
- Evaluation of health risk from mixtures of common drinking water contaminants and mixtures of by-products of alternative disinfection processes, 1984
- Method to distinguish initiation from promotion activity of liver carcinogens, 1985
- Evaluation of validity of extrapolation models for tumor promotors and initiators, 1986
- Relationship of tissue necrosis at high-dose to biochemical effects at low-dose in kidney and liver, 1988

Long Term Trends

Over the next decade, identification of both chemical and microbiological agents in drinking water should have progressed to the point that data gaps are few and well-characterized. Increasing in importance will be refinement of detection methods for these agents, as well as improvement in the ability to predict risk of disease from these agents. The search for better indicators of human exposure and responses to environmental contaminants will become an important issue, as well as increased understanding of toxicity of mixtures of chemicals in contaminated water supplies.

Another major issue over the next ten years will be defining the extent and character of the reactions of disinfectants with aquatic humic materials, and the nature of organic halogen and oxidation by-products that are formed during and after treatment. The physical and chemical factors that influence the reactions must be identified and treatment practices developed in response to estimated health risks from this source.

In the health effects area, there will be increased emphasis on improving methods to extrapolate from toxicological data to risk based on relevant end points, developing biological markers to detect the presence of harmful chemical or microbiological agents, characterizing additive or synergistic effects from mixtures of chemical agents, and improving risk estimation methods through study of cancer initiators and promoters or chemical structure-activity relationships. Lack of toxicity data (e.g., subchronic studies of animals are lacking for most chemicals) and lack of evaluation of human exposure and associated responses are major information gaps. Human data will be needed for verification of various gaps. Human data will be needed for verification of various risk evaluation procedures. EPA is currently exploring the use of epidemiological studies to resolve some of these gaps in data.

Health risk assessment procedures developed today will be strengthened, refined, and validated as time and research continues. Their ultimate utility will depend upon the basic research in cell biology, toxicology, epidemiology, and pharmacokinetics, and the development of short-term screening and assessment methods in toxicity, reproductive toxicity, and carcinogenicity. Emerging scientific opportunities will include biological monitoring of human tissues and fluids, subclinical evidence of various toxic endpoints, and screening assays for potentially carcinogenic compounds. One of the potentials lies in the further detection and characterization of interactions between chemical or biological agents and human genes which control the development of cancer (oncogenes).

The current knowledge base for predicting the impacts of groundwater contamination is limited to a few organic chemicals in a few well-characterized hydrogeologies. The need to develop a data base for the many more chemicals of interest and the less-characterized hydrogeologies will certainly continue over the next five to ten years, or longer.

The realization in the last five years that the deeper subsurface has significant quantities of microorganisms as well as the emergence of new genetic manipulation techniques provides the opportunity for many methods of groundwater cleanup. Such methods may some day provide a dramatic, cost-effective way for dealing with groundwater contamination.

Within the next decade, monitoring systems for the measurement of existing Maximum Contaminant Level (MCL) contaminants should be almost routine at the state/local level. Concurrently, the quality assurance techniques and materials required for certification of laboratories under the Safe Drinking Water Act should be fully operational for the existing regulated contaminants.

The need to measure for a wide variety of toxic organic compounds at extremely low concentration levels is emerging as an issue of enormous importance. Cost effective methods that are comparatively easy to use by state and local personnel are needed for a large number of organic chemicals, including intractable and highly refractory compounds which are difficult to recover from water. Closely related to this analytical need is the accompanying requirement for quality control and performance evaluation samples, especially for groundwater supplies contaminated by refractory organic compounds.

A new issue coming to the forefront is the need to develop and adopt additional microbiological indicators that can serve as viable measures of the safety of drinking water supplies for human consumption. This will be especially important if disinfection techniques other than chlorination become commonly practiced. Ideally, surrogate test procedures could be developed that could at least be used as screening techniques to determine the quality and safety of a drinking water source.

Multi-media monitoring for toxic organic substances at extremely low concentration levels (parts per trillion and parts per quadrillion) produce data of high quality for use by decision-makers on health-related issues should be a major agency goal for the immediate future. These monitoring techniques will also accommodate the newly regulated contaminants that will be added to existing lists.

Use of simpler, less-complicated and costly analytical instrumental techniques, the development of additional microbiological indicators, and the application of surrogate/screening procedures, will make environmental monitoring for state/local personnel a more attainable goal for providing a high quality and safe drinking water.

The combination of reduced costs and rapid advances being made in instrumental techniques, such as high resolution (capillary column) gas chromatography, gas chromatography/mass spectrometry, and high performance (micro column) liquid chromatography, and the rapidly growing use of computer systems and their almost routine application in every day life, represents the opportunity to provide major breakthroughs in the quantitative measurement of toxic organic substances by state/local personnel.

9 Water Quality

Water Quality

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Background

Major Research Topics

Water quality-based standards: What information and tools are needed to support implementation of state water quality standards?

Ocean disposal: What data is needed to assess and control environmental degradation that may result from ocean disposal of waste?

Short-term biological toxicity tests: What short-term biological tests can be used to assess the biological and human health implications of wastewater and sludge?

Sludge disposal: What technical and scientific information is needed to reduce the cost of sludge disposal and to establish use criteria for sludges from municipal waste treatment?

Treatment systems: What data and technologies are needed to assure cost-effective design and operation of wastewater treatment systems?

Long Term Trends

9 Water Quality

Introduction

EPA's water research program develops the scientific bases for the agency's water pollution control programs. This includes support to the Office of Water Programs and assistance to state and local government. Research provides the information and methodology required to establish effective regulatory programs to protect fresh water and marine environments and to assure use of the most cost-effective wastewater treatment technologies.

EPA's water-related research is directed at both ambient water quality and drinking water. Drinking water is addressed in a separate chapter of this report. Five high-priority water quality topics are addressed: water quality standards implementation, ocean disposal, short-term toxicity testing, sludge disposal and wastewater treatment technology. For drinking water, the key topics are: distribution system contamination, disinfection by-products and ways of improving estimation of health risk.

The topics discussed in this report represent thematic areas of highest priority and of growing concern, but do not include all ongoing research related to EPA's water protection mission. A number of issues which were discussed separately in last year's *Outlook* have been consolidated into one topic on implementation of state water quality standards. This will make clear the rationale behind, and interconnections of, the separate sub-issues.

The water quality research program for fiscal year 1984 is allocated a total of $24.2 million. This total is divided among three subgroups: water quality research, $15.7 million; municipal wastewater research, $7.9 million; and industrial wastewater research, $1.6 million. The total resources for the water quality program are distributed among the major research areas as follows: engineering and technology, 23%; environmental processes and effects, 48%; monitoring systems and quality assurance, 16%; health effects, 11%; and scientific assessment, 2%.

Legislative Mandate

The Clean Water Act and the Marine Protection, Research and Sanctuaries Act both address protection of the Nation's water quality. The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of United States' waters. The objective of the Marine

Protection, Research and Sanctuaries Act is to regulate the types and amounts of materials which, if dumped into ocean waters, would adversely affect human health, welfare and amenities or the marine environment, ecological systems and economic potential.

Background

Although much progress has been made in establishing a scientifically sound information base for making water quality management decisions, major information needs remain. EPA research will focus on the following areas:

First, national water quality criteria developed by EPA provide only limited guidance for certain water bodies. Because the relationships between instream criteria and water uses are imprecise, it can be difficult to define the benefits of achieving water quality standards for particular water bodies.

Second, there are a number of gaps in our understanding of the transport and fate of contaminants in the oceans, of the impact of these contaminants on aquatic life, and of waste treatment options as these relate to ocean dumping.

Third, less expensive, short-term biological tests are needed to facilitate implementation of water quality standards and the NPDES Program. Such tests are needed by EPA and the states to assess water quality and by dischargers to control the toxicity of effluents. Such tests would offer an alternative to the expensive and time-consuming process of dealing with complex waste mixtures on a chemical-by-chemical basis.

Fourth, states and municipalities need better methods for reviewing sludge disposal options, including the possible human health impacts of each option.

Finally, to help the agency, and state and local governments use wastewater treatment technology more effectively, additional scientific information on more efficient design of new plants and less costly ways of upgrading existing plants to achieve compliance with permit limits are needed.

Water quality-based standards: What information and tools are needed to support implementation of state water quality standards?

The Clean Water Act (CWA) delineates two types of regulatory requirements to restore and maintain the quality of the Nation's waters. Technology-based guidelines set uniform national requirements for discharges by industries and sewage treatment facilities, and are applied without regard to the type of water body or to quality of the water receiving the discharge. Water quality-based standards, which have been adopted by all 57 states and territories, define the uses to be made of water (such as public water supply, propagation of fish and wildlife, recreation, agricultural and industrial purposes, and navigation) and the criteria to protect the uses. Criteria are acceptable qualitative or quantitative estimates of water constituents which should ensure that the use is attained. Ambient water quality criteria for the protection of human health compliment aquatic life criteria in providing a scientific basis for the formulation of water quality standards. Guidance to the states for modifying human health criteria on a site-specific basis is needed to provide the flexibility essential for standards implementation.

The priority given in the last ten years to developing technology-based controls meant that EPA placed less emphasis on developing the information base and tools needed to support a water quality-based approach. Although minimum technology requirements have improved the overall quality of the Nation's rivers and streams, many water bodies will require additional controls if water quality standards are to be met. One major water quality research priority is solving the technical and scientific problems associated with translating water quality standards into permit conditions.

The remaining water pollution problems will likely be among the most difficult to address, especially if they are caused by toxic substances, non-point sources, or other factors such as low flow which limits the available capacity of the water body to assimilate pollutants.

Although some states have made significant progress in developing water quality-based controls, scientific information is still needed to facilitate pollution control decisions. There are three major aquatic life elements and two human health concerns related to implementation of water quality standards which EPA research is addressing:

Use attainability: In order to ensure that water quality goals are ecologically attainable, an orderly process is used to classify possible uses and levels of use, determine attainability, set ecological requirements for the use, ensure that these requirements are met and, finally, monitor for results. The basic elements for a "use-based" approach are well understood, but each step in a "use attainability analysis" requires specific scientific knowledge and techniques.

Site-specific criteria and complex effluent toxicity testing: To implement water quality-based controls, state permitting agencies need better information and field validated protocols to establish: single pollutant criteria that account for local water quality characteristics and varying sensitivities of local aquatic species; criteria for single pollutants which account for interactions between chemicals in known pollutant mixture; and criteria for mixtures unknown pollutants and toxicity control for complex effluents.

Wastewater allocation: The wasteload allocation (WLA) process is the basis for permit limitations for individual dischargers, in which margins of safety, distribution of treatment burdens and non-point source controls are considered. Many water quality models are available, but most have not been adequately field tested and are limited in the range of application. Dynamic WLA models are needed that can be used to accurately assess complex multiple discharge situations.

Human health controls: An association has been shown between infectious disease incidence in swimmers and water quality as determined by bacterial indicators. However, the identification and origins of the disease agent(s) have not been determined. Recent findings suggest that the traditionally recognized pathogens may not be responsible for the observed disease. The occurrence of particulate matter, probably derived from wastewater, also influences the exposure patterns of swimmers by allowing infectious-dose levels of organisms to be ingested at one time. Methodology and field studies need to be conducted to identify the agents involved and to evaluate control options.

Human health criteria: Criteria for the protection of human health are important where the designated use for a water body includes public water supply, the taking of fish for human consumption, or recreational use. Depending on the nature of a pollutant, human health criteria may be less stringent or more stringent than criteria which protect aquatic life. Because use designations vary, human health criteria also need to be modified on a site-specific basis.

In addressing these information needs, EPA's research is fulfilling its responsibility to provide current technical information to EPA regulatory offices, and regions and states concerning aquatic life and human health protection. In addition to providing new information, EPA evaluates, integrates and synthesizes the research result, of other organizations. EPA has the lead role in the development and evaluation of bioassay methods for the protection of aquatic life. The agency also has a shared responsibility in the evaluation and assessment of threats to human health from toxic chemicals. Other agencies supporting research in this area include the Food and Drug Administration and the National Institutes of Health.

EPA must now provide the means to approach the difficult remaining ambient water quality problems. These often involve mixtures of toxic chemicals from many sources and highly variable seasonal flow conditions. Solutions to such problems will require the definition of site-specific goals and the application of science and technology as well as effective resource management. The following is EPA's research strategy:

Use attainability: To determine those uses presently attained in an aquatic ecosystem, there are three complementary tasks: The first is to characterize uses in measurable biological and ecological terms. The research approach will be to select key measurable factors that describe important characteristics to determine which of them are linked to particular uses. Preliminary numerical limits associated with uses will be tested for applicability and variability under field conditions. The second step is to determine what uses are attained. The research approach will be to evaluate available means of assessing the health of an aquatic community, based on structural and functional attributes of biological organisms, and by determining the utility of various indices of ecological health. Data analyses and interpretation of results will be emphasized. In cases where designated uses are not attained, a third step is to determine the environmental factors (e.g., water quality, minimal flow, habitat destruction) that commonly limit uses. This involves evaluating the relationships among physical habitat, water quality and biological variables under field conditions, and developing laboratory and field bioassay techniques for assessing environmental impacts.

In degraded water bodies, knowledge about potentially attainable conditions is required to set appropriate management goals. Current and new knowledge about the constraints and potentials of different water bodies will be combined into an integrated assessment methodology. The research approach involves investigating related factors that control water uses. Research on biological/ecological potential will: develop and test methods to regionally classify water bodies so that states can use the information to generalize potentials of systems and thus lessen the need to survey each site in detail; develop and test methods to assess physical habitat requirements, including sediments, that are necessary to support aquatic life uses; develop new methods and adapt existing methods to assess the water quality requirements necessary to support aquatic life uses.

Site-specific criteria and complex effluent toxicity testing: An intensive research effort will develop and field test a tiered approach to setting criteria that will integrate the following methods: *Individual pollutants* - Field validation of site-specific methods for accounting for local chemical and biological conditions will be completed in 1985. Because present criteria have been developed under steady-state laboratory toxicity test conditions, methods will be developed to extrapolate to fluctuating exposures. *Combined pollutants* - Protocols will be developed and field evaluated for deriving water-quality criteria for single pollutants which account for synergistic and antagenistic effects with other pollutants by determining the sublethal effects of toxic chemical mixtures on aquatic life. *Complex effluent toxicity* - A significant amount of acute data has been generated on the toxicity of effluents. EPA will develop a consistent approach for structuring this testing, verifying results, and using it to support permitting decisions. Toxicity testing and validation will be field oriented. Toxicity reduction approaches, using standardized bioassays and the concept of toxicity units, will encourage the management of industrial pollutants at the source. *In-stream toxicity* - To implement the water quality-based approach in water bodies with complex effluent discharges, and discharges that are grouped so closely together that biological recovery does not occur between them, permit writers must quantitatively understand the link between a specific effluent and its biological/ecological impact. Field research will develop toxicity tests that can be related to stream impact and used to aid in identification of toxicant effluents as well as providing overall toxicity limits.

Often a permit writer needs to use various combinations of criteria and toxicity testing together with in-stream toxicity impact assessment. Research will focus on developing a tiered approach, that integrates pollutant specific techniques, combined pollutant approaches and whole effluent toxicity testing procedures. Each has limitations and must be evaluated in conjunction with the others. Emphasis will be on field testing of methods and improving data interpretation techniques for a range of parameters including toxicity, pesistence, hydrology and bioaccumulation.

Wasteload allocation: Wasteload allocation research will focus on developing and field testing dynamic models that predict transport and fate, as well as environmental exposure, for toxic pollutants. Models will accommodate probabilistic inputs and thus better reflect the effects of inherent variability in treatment as well as receiving streams. Continued development of environmental process rates and related data bases that are needed for WLA models is planned. In gross terms, non- point sources are the largest cause of biological oxygen demand, nutrients, and sediments, and may contribute significant loadings of heavy metals and other toxic substances in the Nation's water bodies. Research will continue to develop techniques for establishing "innovative" permits for seasonal and multiple discharges. The difficult task of developing WLA strategies for complex, multiple discharge sites and relating complex effluent parameters to impacts on water uses will require a longer term effort. Emphasis on chemical species in effluents, derived from field sampling, will be used as preliminary assessments of potential hazards. The proposed evaluation studies will involve cooperative efforts between EPA and local agencies.

Human health controls: Specimens from swimmers experiencing infectious disease will be collected and evaluated for etiological agents. Methods to identify emerging viral agents of waterborne gastroenteritis will be developed. In addition, the significance of water-borne particulates on recreational disease occurrence will be determined in regard to particulate origin, composition and pathogen adsorption, and protection. Investigators would like to use existing short-term health tests to determine whether or not a site receiving a large number of chemical contaminants is a public health risk. Research will provide field tested and validated methods in a manual that discusses protocols and interprets strengths and weaknesses of health effects biomonitoring techniques. The manual will help investigators select and interpret the appropriate tests in order to develop water quality-based controls.

Human health criteria: A study will be made to determine the local availability of information which would be needed to carry out site-specific criteria modification, and to determine the degree of specificity which can be achieved. The protocol will be revised accordingly, then tested using site-specific data from a wide range of water bodies to ensure that the resulting criteria are realistic and protective. Guidelines for assessing the health effects of chemical mixtures, currently under development, will be completed and used as a basis for expanding the current site-specific criteria modification protocol. This scientific information will also serve to guide research on technology for mitigating discharge problems related to public health.

Major expected results from planned research include:

Use attainability

- Pilot test in two stages prototype regional or geographic approaches for determining the biological potential in stream ecosystems, 1985
- Provide time-varying Dissolved Oxygen level (DO) requirements for aquatic life, 1985
- Define alternative water uses, such as fisheries potential, in terms of biological characteristics and physical habitat requirements, 1986
- Develop, field test and publish attainability analysis methods for lakes, estuaries, coastal waters, 1989

Site-specific criteria

- Evaluate relationships between chronic toxicity of effluent in receiving water and in the laboratory, and develop and field test an in-stream toxicity protocol, 1984.
- Incorporate fluctuating exposure conditions into the National guidelines, 1985
- Develop a biological approach to monitor lethal and sublethal effects of chemical mixtures (combined pollutant toxicity), and a protocol for using complex effluent toxicity measured for wasteload allocation, 1986
- Publish a tiered approach to measuring and controlling effluent toxicity that integrates single pollutants, combined pollutants, generic pollutants, and in-stream methods into a protocol that is usable for a range of field situations, 1988

Wasteload allocation

- Produce a field-tested generic toxicity protocol, using effluent bioassays, for toxicity wasteload allocation, 1986
- Develop wasteload allocation strategies for complex, multiple discharge situations, 1986
- Produce a field-tested dynamic WLA model for conventional and toxic pollutants that incorporate time-variant exposure including non-point source contributions and loading variability, 1988

Human health controls

- Produce health effects bioassay methods manual for determining whether receiving streams meet waste allocation, 1985
- Assessment of data on water particulates in swimmer-disease occurrence, 1985
- Identification of emerging waterborne pathogens, 1986

Human health criteria

- Provide guidelines to states for assessing human health risk of chemical mixtures, 1985
- Protocol for site-specific modification of human health criteria for single pollutants and mixtures, 1987

Ocean disposal: What data is needed to assess and control environmental degradation that may result from ocean disposal of waste?

For the next decade, the role of EPA research in the ocean disposal program will be highly varied and complex to meet the requirements of Sections 301(h) 403(c) of the Clean Water Act, and the Marine Protection, Research and Sanctuaries Act. Understanding the ecological consequences of ocean outfalls and ocean dumping will be needed to guide future public policy, satisfy international marine treaties and to protect and enhance, where possible, coastal fisheries resources. A major need is to gather facts on the relationship between disposal costs and protection of marine life. EPA's research is carried out in collaboration with the National Oceanic and Atmospheric Administration and the U.S. Army Corps of Engineers.

Available information on the transport and fate of ocean disposed materials is limited, and long-term data on sublethal effects of these materials are practically non-existent. The EPA research program will continue to provide an information base and assessment methods for the development of a sound regulatory program. EPA's ocean disposal research will: develop models of the transport and fate of specific classes of pollutants, determine the bioavailability of sediment-associated pollutants to benthic and pelagic organisms, determine the effects of sediment-associated and water-borne pollutants on marine organisms, measure rates and factors regulating pollutant degradation, and provide monitoring protocols to assist EPA enforcement operations and other federal agencies with state-of-the-art anticipatory monitoring technologies.

There are two major issues with regard to ocean dumping — the dumping of sludges and other materials from barges and the direct discharge, through pipes, of effluents into the ocean at "outfalls." To support EPA's ocean dumping permit program, our research will develop and verify laboratory and field procedures to better assess impacts associated with disposal of municipal sewage sludge, dredged material and industrial wastes on ocean ecosystems.

Our ocean outfall research program will support the agency in deciding the extent to which it can allow municipal wastewater discharges through ocean outfalls without secondary treatment. Monitoring and technical support to EPA's regions will be emphasized.

The ocean dumping research approach will develop procedures and methods together with field verification studies. Research on dumpsite characterization will identify key information needed to characterize both sites and wastes, and develop and field test a protocol for collection, synthesis, and integration of this information. Assessment methods will be developed for two purposes. First, for waste evaluation, protocols will be developed for chemical, physical and biological characterization of wastes. Second, for hazard assessment, protocols will be developed for effects and exposure assessment.

Protocols for dumpsite monitoring will be developed for permit/ compliance monitoring of water, sediments and biota, and for natural population, community and system responses to best management practices. Field validation of hazard assessment protocols will be integrated with trend assessment monitoring. Conceptual models will be developed to assist in understanding processes of biological degradation, recovery and enhancement, to assess pollutant interactions in complex waste mixtures as determinants of stress, and to evaluate the integration of biological effects across different ecosystem components.

Engineering aspects of the treatment prior to disposal, transportation, and method of placement of materials at dumpsites will be evaluated in the field. A major case study at a deep-water dumpsite will be used to verify assumptions and assessment procedures developed by EPA research. This field study will complement a similar ongoing EPA project at a shallow-water, nearshore dumpsite receiving dredged material.

EPA's ocean outfalls research will apply models of assimilative capacity to reveal the environmental factors that control degradation to marine ecosystems. EPA research will evaluate and field test existing models and develop new ones, if necessary, to determine the impacts of waste materials on fish and other marine life. Also, researchers will seek to discriminate among the effects of different materials in discharges, including organic chemical contaminants and nutrients.

Interactions among waste substances may determine the gross toxicity of waste discharges. Research will identify those contaminants whose interactions pose the greatest ecological threats, and subsequently determine which treatment options are most effective in terms of controlling particular disposal impacts. The need to field validate effluent toxicity estimates is a key task in EPA's ocean outfall research that will receive increased attention. One validation method will be to compare bioassay results of sediment samples (collected at increasing distances from an outfall pipe) to the structure of the benthic community. The effectiveness of sewage treatment processes to modify the levels and forms of nutrients, BOD, pH, suspended solids, priority pollutants, and coliform content will be evaluated in relation to their impacts on marine environments.

The research will determine the toxicological properties of municipal wastes that have received a variety of primary, secondary and unconventional wastewater treatment. The toxicity of particulates to benthic organisms from the different treatment processes will be added to unpolluted reference sediments and the pelagic biota ecosystem through simulators will be examined for adverse impacts from the dumped materials.

Major planned research products include:

- Final site designation technical guidance document, 1985
- Dumpsite biomonitoring methods manual, 1985
- Protocols for characterizing the transport and fate of pollutants common to ocean outfalls, 1985
- Techniques for characterizing benthic conditions and ecological impacts near ocean outfalls for use in setting permit conditions, 1986
- Report correlating the type and level of effluent treatment and environmental impact of the receiving environment, 1986.
- Manual for evaluation of a waste proposed for ocean dumping, 1986
- Chronic/partial chronic bioassays for sewage sludge, 1987
- Development and field validation of hazard assessment methods, 1988
- Develop, field test, and publish monitoring techniques for use in mandatory monitoring programs, 1988
- Engineering aspects of sludge treatment, transport and disposal, 1989

Short-term biological toxicity tests: What short-term biological tests can be used to assess the biological and human health implications of wastewater and sludge?

EPA currently regulates the introduction of municipal and industrial pollutants into wastewater and sludges on a parameter-by-parameter basis. Specific chemical methods are used in this effort. However, in the environment, there may be additive effects of multiple toxicants, and the toxicologically significant concentrations of toxicants often lie below chemical detection limits. In addition, specific chemical-by-chemical analysis is difficult, time consuming and expensive. There is good evidence that short-term biological tests, both *in vitro* and *in vivo*, used singly and in tiered batteries of bioassays, can be developed and adapted to a variety of complex chemical mixture toxicity assays in the environment.

A number of bioassay procedures have been published in the scientific literature. Among these are the use of mussels in marine waters as collector/concentrator monitoring devices, embryo-larval fish toxicity tests which mimic results of life-cycle exposures in a matter of days, the use of shrimp and other invertebrates as toxicity monitors, and the use of micro-organisms. Cellular and subcellular biochemical assays have been identified and correlated to both environmental contamination levels and pathological changes in the whole organism.

EPA will continue to evaluate, improve and standardize existing methods, and incorporate them into monitoring protocols complete with quality assurance procedures. Such tests are especially useful with complex mixtures of contaminants. Toxicological testing methods for human health hazards, when applied directly to sludges, industrial and municipal effluents, and to receiving waters, could indicate appropriate routes of use or disposal for sludges and whether certain effluents could preclude specific uses of a receiving body of water. This approach will be useful in a variety of applications including: to assess the impacts of sludges and industrial and municipal wastewaters, to determine the need for pretreatment of industrial wastes before entering the municipal wastewater system, and to determine the allocation of waste loading for particular stream segments among multiple dischargers.

The knowledge base in using bioassays for environmental monitoring is insufficient to support its widespread application. The exact pharmacodynamics, (i.e., contaminant uptake rates and subsequent compartmentalization within the organism and depuration) remain largely unquantified. The normal growth and maintenance of individual species, age groupings, etc., need to be scientifically characterized and standardized. The environmental requirements and pollution tolerance of species must be more accurately defined.

The experience and testing for toxicity effects that has been generated over the past 30 years is enormous. A significant effort to evaluate toxicity results of species other than those traditionally used could ultimately be cost effective and provide valuable results.

EPA has a lead role in standardization of bioassay techniques. It shares with other organizations responsibility for the development of bioassay procedures in environmental monitoring. The use of mussels as collectors has been an EPA development. The embryolarval fish toxicity tests initiated by academia are now being evaluated by EPA. The use of a subcellular metal detoxification mechanism, metallothionine, was also developed in academia. Its potential application was demonstrated for marine pollution monitoring. EPA intends to adapt the technique to fresh water and to define the kinetics of uptake and purge.

EPA is presently active in the research and application of short-term chronic toxicity testing. The agency will have a major role in the further development of chronic toxicity testing because of its responsibilities in developing ways to establish water quality criteria and water quality based effluent limitations. Toxicity limits, an extension of water quality criteria, are expected to be incorporated into the wasteload allocation and permitting processes.

A major focus of the EPA research effort is bioassay modification and adaptation, as well as the evaluation and standardization of the more promising techniques. While substantial data from human health bioassays indicate qualitative correlations between results from short-term tests and more conventional tests, very little data exists for quantitative estimates of risk. Over the next few years, EPA will establish the relationships between an adverse health effect indicator and the production of disease when employed in relation to short-term human health bioassays. Genotoxic effects and target organ toxicities will be used as initial validation of the biological testing approach. The subsequent incorporation of bioassay research material into test protocols and the furnishing of appropriate quality assurance support will continue to be an agency responsibility.

Major planned research products include:

- Provide bioassay testing methods to assess the effectiveness of alternative wastewater control technologies, 1985
- Develop data base for seven-day *Ceriodaphnia* and fathead minnow tests. This will provide comparison data to existing data bases and knowledge on relative sensitivity, 1985
- Define the cause-and-effect relationship between the short-term indicator of adverse health effects and the overt disease, 1986
- Taxonomic identification manual to support biological water quality assessment, 1986
- Evaluate/standardize assay techniques for metallothionine and rapid chronic tests such as *Ceriodaphnia*, 1986

Sludge disposal: What technical and scientific information is needed to reduce the cost of sludge disposal and to establish use criteria for sludges from municipal waste treatment?

About eight million tons (dry weight) of sludge per year are produced from municipal wastewater treatment plants in the United States. The processing and disposal of this sludge accounts for about half of the total operating costs of a typical sewage treatment plant. As a result of the large volume of sludge and the presence of potentially harmful constituents in sludge, municipalities are facing increased economic and public problems with its disposal. Approaches to disposal are needed that will significantly reduce the volume of sludge that must be discharged to the land or ocean and which will result in an acceptable product at lower than the current costs of treatment and disposal. To support agency regulations, research efforts will focus on sludge use criteria, procedures and requirements applicable to the permit process.

The methodology to assess sludge disposal options will be refined, with research developing methods to determine ecosystem resiliency or stresses resulting from disposal of sludges, and to predict the human health effects from exposures to sludge. The latter may include bioassays or other toxicity tests for both health and ecosystems (see preceding topic). Other research will develop information on mitigating risks through sludge treatment or disposal. Such research will include analysis of the cost vs. performance of engineering designs for various treatment and disposal options.

Other sludge-related research will improve our understanding of the sources of heavy metals, toxic organic compounds, and other objectionable constituents in municipal wastewaters. Further research will determine their effects, as well as develop data on processes to inactivate organisms such as parasites, fungi, bacteria and viruses in sludges, and to improve risk assessment methodology for decisions on alternative means of sludge management.

In developing fundamental data about new processes for improved sludge stabilization, volume reduction, energy recovery and use, EPA's research will assess disposal options which reduce volume and mass. A pilot study of an innovative combination of activated sludge, anaerobic digestion and wet oxidation will determine the mass and volume reducing capabilities of this approach. A follow-up large scale evaluation will be run for a sufficient amount of time to determine operating efficiency, performance and cost.

Epidemiological studies have been initiated to evaluate health hazards. Results from these studies will provide data for use in determining the effects on disease occurrence of various treatment processes and application techniques.

Major planned research products include:

- Guidelines for conducting health risk assessments of sludge disposal options, 1985
- Etiological data on infectious diseases from identified sludge pathogens, 1986
- Design guidelines on sludge treatment technologies including innovative anaerobic sludge digestion processes, energy recovery, pathogen reduction, and more efficient thermal conversion processes, 1987
- Sludge quality and volume relationships, 1987
- Standardization of extractive processes for organic constituents by priority classes, 1987
- Standardization of sludge sampling techniques, 1988

Treatment systems: What data and technologies are needed to assure cost-effective design and operation of wastewater treatment systems?

The costs of construction and operation of both conventional secondary and advanced wastewater treatment processes represent major public sector expenditures. To assure effective and least-cost solutions for control of municipal discharges, research must resolve a number of technological issues associated with defining the effectiveness and costs of treatment and management practices in relation to the attainment of water quality standards.

To assure the availability of lowest-cost options for point-source discharges, EPA's research serves as a catalyst for industry. EPA will provide technical evaluations of the costs, performances, and effluent variabilities of various new innovative and alternative technologies at a scale that is sufficient to reduce risks to the design engineer and the locality installing the system. For existing plants, emphasis will be on plant upgrading methods as a cost-effective alternative to new construction. Examples of such alternatives include converting to fine bubble aeration, increasing aeration surface areas and use of high biomass reactors. This research will clearly characterize control options and provide reliable information on these options to those responsible for water quality standards achievement through facility planning, system design, and permit issuance.

EPA's research program will develop data on the costs and performance for a range of innovative and alternative technologies. The research will focus as its highest priority on the identification of low-cost methods to improve existing facilities for smaller communities. Also, research will focus, beginning in 1984, on the evaluation of new design concepts to achieve state discharge permit compliance. The research information will help states to consider variable discharge limits related to stream flow or season of the year.

With regard to the water quality impacts of toxic pollutants, cost/ performance information will be obtained on engineering options for methods of treating the limiting toxic pollutants. This will include evaluations of the role of the municipal treatment plant, including its ability to remove toxic pollutants, as an alternative to industrial pretreatment.

Major planned research products include:

- Characterization treatability of toxic substances in treatment plants, 1985
- Post construction evaluations of life cycle cost savings and energy reduction for innovative and alternative treatment project, 1985-1988
- Evaluation of innovative approaches to upgrading noncomplying facilities and to avoid compliance problems in new treatment facilities, 1987
- Characterization of pollutant removal efficiencies and variabilities and cost of representative municipal and industrial treatment systems, 1988
- Applications of systems analysis approach with select states to optimize costs, reliability and resililency of small community oil large area made wastewater management systems, 1988

Long Term Trends

Most of the water quality issues discussed in the Outlook are expected to require continuing research over a long-term (five to ten years). The two most near-term issues are development of information for permitting based on state water quality standards, and research on wastewater treatment technology. While EPA research in these areas can be applied soon, there will remain many related questions for the future. For example, water quality research in estuaries and research on non-point pollution control practices are not currently high research priorities, but will clearly be required in the longer term.

In the wastewater treatment area, we do not foresee major fundamental changes. The most likely and desirable course lies in application by the states of a systems analysis approach to wastewater treatment. Implementing a systems analysis approach will result in more equitable wasteload allocations, ensure reasonable margins of safety in stream loadings, eliminate over-design of treatment plants, increase treatment reliability and technology, developing and implementing water quality standards, and produce lower lifecycle costs. A major breakthrough in treatment, if there is one, may well come from the use of biological engineering.

One area which is clearly going to require long-term research involves improvement of risk assessment techniques and improved extrapolation of animal health data to human populations. Both the complexity and importance of these subjects will require a long-term effort, and of course, they will be linked to future research being conducted in support of other programs.

While some short-term biological toxicity tests may be developed for use by the agency and industry in the near-term, there are many questions which will require future research. One area of concern will be the interpretation and extrapolation of sublethal effects on test organisms. In cases where tests are designed to detect genetic damage, the interpretation and extrapolation issues will resemble those in the human health area discussed above, with a need to factor in complex ecosystem interactions as well. This work is linked to the broader scientific themes of dealing with discharges containing complex mixtures of chemicals and multiple discharge situations. If water quality can be measured in terms of total toxicity, and controls implemented on a toxicity reduction basis, it may be possible to clean up these types of water contamination in a less costly manner than would be the case using a chemical-by-chemical approach.

Technology information transfer is an important element of a successful research program. The need for effective transfer of results is a major theme which is not, strictly speaking, a scientific issue but which the agency believes is an important one. It is clear that more responsibilities and burdens for water clean-up and, increasingly, protection of clean waters, will be transferred to the states. Therefore, there will be continuing focus on state needs and efforts to insure that research addresses those needs and that results are available to states in an understandable fashion.

Appendix A

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Appendix A

The law requiring the submission of this research strategy document to Congress is Section 5 of Public Law 94-475. The same law also requires that a five-year projection be provided indicating the potential research response to different resource levels.

The following section on resource options includes, as required by the law, descriptions of conditions for high, moderate and no growth. The growth rates associated with these options are zero for no growth, three percent for moderate growth and six percent for high growth. No additional resources are required or expected as a result of this submission. Rather, these growth scenarios are intended, as required by the law, to indicate potential program increases in EPA's research and development.

Resource Options

Toxic Substances and Pesticides

Growth	1984 Current Estimate $30.7 Million Projections 1985	1986	1987	1988
None	35.1	35.1	35.1	35.1
Moderate	35.1	36.2	37.3	38.4
High	35.1	37.2	39.4	41.8

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Investigations into the relationship between a chemical's structure and its chemical, physical and biological properties will be accelerated.

High Growth: Additional efforts will be made to link health and ecological effects with various models that describe the steps in the life cycle of a substance from its production and release to its ultimate destination. Such efforts are in addition to those mentioned under moderate growth above.

Hazardous Waste

Growth	1984 Current Estimate $32.3 Million Projections 1985	1986	1987	1988
None	34.8	34.8	34.8	34.8
Moderate	34.8	35.8	36.9	38.0
High	34.8	36.9	39.1	41.4

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Additional efforts will seek to discover the key factors leading to the failure of soil, clay or synthetic liners for hazardous waste land disposal sites and to investigate alternative disposal/destruction technologies.

High Growth: Techniques to detect and monitor subsurface movement of hazardous waste leachate will be further investigated. Emphasis will be on identifying key early indicators of leachate migration problems. Additional effort will be invested in the development of advanced alternative disposal/destruction technologies.

Air

Growth	1984 Current Estimate $64.1 Million Projections 1985	1986	1987	1988
None	67.3	67.3	67.3	67.3
Moderate	67.3	69.3	71.4	73.5
High	67.3	71.4	75.7	80.3

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Additional work will improve the technology and techniques available for measuring and monitoring hazardous air pollutants.

High Growth: An increased effort will identify more clearly the causes and mechanisms of human responses to air pollutant exposures. This effort will be in addition to that cited under moderate growth above.

Energy

Growth	1984 Current Estimate $15.1 Million Projections 1985	1986	1987	1988
None	14.1	14.1	14.1	14.1
Moderate	14.1	14.5	14.9	15.4
High	14.1	15.0	15.9	16.9

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Efforts to characterize reaction conditions in limestone-injected multistage burner configurations will be accelerated. The information produced will serve to guide the development of more refined (more effective) emissions reduction configurations.

High Growth: The efforts described under moderate growth above will be augmented and accelerated.

Acid Rain

Growth	1984 Current Estimate $15.4 Million Projections			
	1985	1986	1987	1988
None	34.4	34.4	34.4	34.4
Moderate	34.4	35.4	36.5	37.6
High	34.4	36.5	38.7	41.0

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: In the source-receptor relationship area, additional efforts will be made to improve methods for identifying the source of a particle by its "fingerprints." Work with tracers will be accelerated.

High Growth: Efforts to delineate between actual acidic deposition trends and other cyclic meteorologic influences will be advanced and the efforts described under moderate growth above will be accelerated.

Drinking Water

Growth	1984 Current Estimate $23.8 Million Projections			
	1985	1986	1987	1988
None	23.1	23.1	23.1	23.1
Moderate	23.1	23.8	24.5	25.2
High	23.1	24.5	26.0	27.6

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Additional efforts will be initiated to determine with greater precision the potential health effects of those substances that are found in drinking water treated via various disinfection processes. Focus will be on those contaminants that are non-volatile and, therefore, have yet to be investigated in any great detail.

High Growth: The additional efforts cited under the moderate growth option above will be augmented and accelerated.

Water Quality

Growth	1984 Current Estimate $24.8 Million Projections			
	1985	1986	1987	1988
None	26.8	26.8	26.8	26.8
Moderate	26.8	27.6	28.4	29.3
High	26.8	28.4	30.1	31.9

No Growth: The program will proceed as described in this Research Outlook.

Moderate Growth: Efforts to develop flexible protocols for determining site-specific water quality will be accelerated as will efforts to transfer such capabilities to state and local environmental officials.

High Growth: Efforts will be accelerated to develop regimens for characterizing the ecosystems of potential ocean outfalls and dumping sites. Investigations of early indicators of potentially negative ecosystem responses will also be accelerated. These activities are in addition to those listed above under moderate growth.

Appendix B

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Appendix B

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